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# VERIFICATION OF FLEET NUMERICAL WEATHER FACILITY'S ANALYSES AND FORECASTS OF POTENTIAL MIXED LAYER DEPTH

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# VERIFICATION OF FLEET NUMERICAL WEATHER FACILITY'S ANALYSES AND FORECASTS OF POTENTIAL MIXED LAYER DEPTH

BY

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## ABSTRACT

In 1962, Fleet Numerical Weather Facility started distributing mixed layer depth forecasts and analyses to the Fleet on an operational basis. The present method of computing this mixed layer depth is discussed and a verification is conducted for the months of October, November, December, 1965, and January, 1966, to determine its accuracy and usefulness to the Fleet.

The results show that 42 percent of the forecasted and analyzed values are in the excellent (± 40-feet) range, while 26 percent of the values are in the poor (greater than ± 100-feet) range. The distribution of errors indicates that the majority of the positive errors occur in the Western Pacific, while the negative error concentration is in the Eastern Pacific. Conclusions indicate that 20 percent of the time the forecast will be detrimental to Fleet use.

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## 1. INTRODUCTION

A knowledge of the subsurface thermal structure is of extreme importance to the Navy today in light of the present submarine threat. It is, therefore, of prime importance that an accurate and reliable system of forecasting the mixed layer depth in the oceans be perfected. This system is of prime concern to the operational planners of today to provide proper protection and accurate convoy routing. Knowledge of the subsurface thermal structure and thereby an increased knowledge of the oceans is a foremost consideration of the fishing industry and to those concerned with the potential source of natural resources in the oceans.

In recent years several schemes have been developed to attempt to forecast the mixed layer depth. These schemes have developed around to main ideas. First is a statistical approach that incorporates measured atmospheric parameters and correlates these with fluctuations of the mixed layer depth. Another approach, and perhaps a more logical one, deals with the driving forces of the ocean and estimated these forces and their effect on the subsurface thermal structure, permitting a forecast of the mixed layer depth. It is with the latter that this paper is concerned. Although several schemes have been developed, not one of these has been subjected to an extensive verification. Such a verification is the purpose of this paper. The actual accuracy of forecasts and the accuracy tolerable for operational purposes are totally different from the standpoint of the user of the products. The attainable and acceptable accuracies must be determined if the value of this program of forecasting mixed layer depth is to be measured.

To understand the problems involved in predictions of the mixed layer depth, it is important for us first to realize all of the factors that influence it. These factors include clouds, wind, currents, internal waves, tides, bottom topography, ice, etc.. Because of the many and varied influences on the mixed layer depth, one system based on a statistical approach for forecasting accurately the mixed layer depth in all the oceans would be not only impractical, but almost impossible.

In 1962 the U. S. Navy Fleet Numerical Weather Facility, situated on the grounds of the U. S. Naval Postgraduate School as a tenant activity, undertook to provide operational forecasts of ocean parameters to the Fleet on a regular basis. Fleet Numerical Weather Facility recognizes the complexity of oceanic forecasting, considers carefully the obvious controlling factors, and relates them through a cause and effect system to the mixed layer depth. The forecasts/analyses are accomplished by use of high speed computers together with a numerical model designed to approximate the conditions of the ocean.

An attempt will be made here to explain in some detail the approach and methods employed by Fleet Numerical Weather Facility and to provide a verification of the analyzed and forecasted mixed layer depth. Its usefulness and accuracy will be scrutinized to determine its value to the Fleet.

The data selected for this initial verification was confined to the Pacific area because the Atlantic area forecasting is still under-

going extensive changes to achieve better accuracy. The Pacific area forecasting has reached what Fleet Numerical Weather Facility personnel consider is a higher degree of accuracy and so was a logical choice for the confines of the data to be analyzed. One small segment of Atlantic area data was analyzed for a special project to be described later. The computer analyzed charts were chosen because they are the product available to the user aboard ship. A meaningful verification for the user is the main intent of this study but verification for other applications is also an inevitable by-product.

## 2. FLEET NUMERICAL WEATHER FACILITY METHOD OF COMPUTING MIXED LAYER DEPTH

As previously stated, the Fleet Numerical Weather Facility uses a numerical approach to the problem of ocean forecasting. It must be understood that mixed layer depth is only one of their oceanographic products. Others include wave height, sea surface temperature, currents, and ocean fronts. Mixed layer depth is, however, one of the more important products. The following explanation will show just how the numerical method is employed to arrive at a result in this area of ocean study.

The spacing between the intersections of the regular grid array used for computations is approximately 200 nautical miles. The spacing can be changed, but for the density of the data available, it seems to be the optimum. The numerical analyses are made from data located at intersections of this regular grid.

Assume there is an accurate analysis of the mixed layer depth for the previous 12-hour period. This analysis will constitute a first guess field, or in other words, the best approximation of the mixed layer depth prior to applying the relationships that have operated for the past 12 hours to cause variations. The first guess is modified in several ways to arrive at the analysis for the present or the forecast for the next 12 hours.

The first change made to the last analysis or the first guess is to compute the change in the mixed layer depth that would occur due to convergence or divergence of ocean currents during the last 12 hours. This term can either raise or lower the first-guess field. The actual computation is accomplished by using the

numerical approximation to convergence or divergence of

$$\Delta D = (u_1 + u_3 - u_4 - u_2 + v_1 + v_2 - v_3 - v_4) \frac{D}{4L}$$

where u and v are the east and north components of the computed current, D is a constant (200), and L is the grid mesh size (approximately 200 miles). It is pointed out that the computation is based on the computed currents which themselves are not verified by direct current measurements but are verified indirectly by use of the sea surface temperature analysis in the following manner. From the sea surface temperature analysis, a temperature change for 24 and 48 hours is determined. From these changes, the local changes computed from the air/sea heat equations are subtracted. If the difference between these two correlates well with the advection changes, then the computed currents are assumed to be reasonably correct.

As $\Delta D$ is computed for each grid point it is added or subtracted, and the result is a new field which is then altered by consideration of effects of convective stirring. Convective stirring can have only the effect of increasing the mixed layer depth. The actual computations for convective stirring are of the form:

$$K_1 = \frac{K(T_0 - T_{12})}{T_0 - T_{600}}$$

where $T_0$ = sea surface temperature at the present

$T_{12}$ = sea surface temperature 12 hours ago

$T_{600}$ = Temperature at 600 feet

K = numerical constant

If the term $(T_0 - T_{12})$, the change in sea surface temperature over a 12-hour period, is positive then the mixed layer depth is not changed, but this results in a transient thermocline which is reflected on a separate chart. A negative number from the computation adjusts the computed field of mixed layer depth.

This computed field is then compared to climatological mean data for the current month. If a difference between the climatology and the computed field exists, the field is moved up or down 15 feet toward the climatological mean value. The figure of 15 feet was arrived at by taking the average difference between the maximum and minimum monthly climatological layer depth, and then allowing this difference to be eliminated in steps over one-half of a month. This step tends to eliminate any extremely large differences from the mean monthly values of the mixed layer depth.

At this point forced mixing by wave action is considered. This computation is completed by considering the wave and swell characteristics as analyzed by the computer. It selects data for the last 36 hours at a given grid location and computes the depth of the mixed layer due to this wave action. This computation is of the form:

$$D_W = K_1 H_W + K_2 H_s .$$

$H_W$ and $H_s$ are sea and swell heights, respectively, and $K_1$ and $K_2$ are constants. The computer uses a mean weighting process which weights the oldest information the least and the newest information (i.e. present wave and swell analysis) the most. The forced mixing term can act only to increase the mixed layer depth, and,

therefore, the computed depth is compared with that in the field. Only if the mixing term gives a greater depth than the previously computed field of mixed layer depth is a change in this field made.

The layer depth as indicated by the bathythermograph is selected through determining the depth where the temperature is 2 degrees F (approximately 1 degree C) less than the sea surface temperature. If this depth does not fall exactly at a significant (reported) depth on the BATHY message, the computer takes the previously reported significant depth as the actual layer depth. If the bathythermograph indicates no layer exists, then the last reported depth or 600 feet, whichever is less, is recorded as the layer depth. This puts a maximum depth limitation on the layer depth which is unrealistic.

The next step involves the comparison of observed data with the computed field. The introduction of the bathythermographs from Navy ships and Ocean Station Vessels is accomplished by first making a gross error check of all the messages received during the last 12-hour period. Those messages that are incomplete, that have a time error, that are in the Southern Hemisphere, or in which the difference between the reference temperature and the sea surface temperature is greater than 4.5 degrees are rejected. Those remaining are used to alter the analysis. This alteration is accomplished by looking at each BATHY message and then comparing the layer depth to the already computed field at that latitude and longitude. If a difference exists, the four grid points which surround the location of the bathythermograph are moved 30 feet toward the BATHY value of the layer depth. This 30-foot figure was

arrived at by noting that the standard deviation of error in mixed layer depth due to internal waves at its average maximum is 30 feet.

This comparison process is carried out for each bathythermograph reported three times and a maximum adjustment of 90 feet (30 feet each time compared) can be made, but this will be adjusted by a smoothing operator. Each of the three times all of the BATHYS are compared with the field, the field is smoothed twice by a 1/8 smoothing operator to eliminate the short period fluctuations and discontinuities which occur.

The analysis field is the basis of the 24-hour forecast. To arrive at a forecast, which is updated every 12 hours, it is assumed that the heating or cooling used in computing the sea surface temperature (and hence any convective stirring), and the convergence or divergence will remain the same for the next 12 hours. These are reintroduced at each grid point to give an alteration to the analyzed field. The mean forecasted waves for the next 24 hours are allowed to operate on this field and the result is a 24-hour forecast of the mixed layer depth.

## 3. ANALYSIS PROCEDURES AND DESCRIPTION OF DATA

For verification of the mixed layer depth analysis and forecast, the four months of October, November, December, 1965, and January, 1966, were utilized. All of the bathythermographs received during this four-month period were tabulated by months using a standard format (Figure 1). With the latitude, longitude, and mixed layer depth recorded, the charts for each day were employed to extract the analyzed and forecasted mixed layer depths.

Use of a computer was considered for this problem due to the large amount of repetitive analysis that was necessary. This was ruled out for several reasons, the more important one being that more familiarization with the results would be achieved by actually doing the manual computations.

The bathythermograph data received from Fleet Numerical Weather Facility was in the following format.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| BATHY | 1401 | 1 | 326 | 184 | 580 | 572 | 10571 | 16550...... |
| | Ya | G | La | Lo | b | OO | ZZ Tz | ZZ Tz |

Y - day of the month<br>
a - month<br>
G - octant of the globe<br>
La- latitude<br>
Lo- longitude<br>
b - reference temperature<br>
OO- sea surface temperature as indicated by the BATHY<br>
ZZ- depth<br>
Tz- temperature at depth indicated

Using the mixed layer depth as indicated on the bathythermograh as a reference, both the forecasted and analyzed values (as interpolated for this location from the chart at the same time) were subtracted from it to derive the respective error values. The error

can be either positive or negative. According to the described procedure, a positive value of the error indicated that the actual observed layer depth was deeper than that forecasted or analyzed. This error was the primary factor used in the verification procedures.

The errors were calculated and recorded as to their frequency of occurrence within a given depth range. Recording was done on a monthly basis and then a composite was calculated to show the frequency of occurrence for the entire four months.

In total, 4646 BATHY messages were received during the period involved in the study. Of this number, 13.7 percent were unusable due to either transmission or encoding errors. The charts for analyzed mixed layer depth for the dates 17-24 October, 1965, and both the analyzed and forecasted charts for 3 December, 1965, were not available for consideration. The bathythermographs for those days were omitted for the part of the analysis for which the charts were missing. A tabulation of the data used is shown in Table 1. Of the total BATHY messages that were transmitted, 3740 were used in the verification of the analyzed and 4010 were used for the verification of the forecasted mixed layer depth.

For the month of October, 1965, 8.5 percent of the 954 BATHY messages contained errors and were not utilized. Due to the absence of charts for the analyzed layer depths for 17-24 October only 685 BATHYS were used for this verification, while 869 were used in the forecasted procedure. This is an average of 28 usable bathythermographs per day from the North Pacific Ocean, which is, to say the least, a meager amount of data with which to work. The data are

concentrated heavily in areas of primary naval operations. The only consistent information received from the broad expanse of the Pacific Ocean is that sent by the three Ocean Station Vessels.

During November, 1965, there were 840 BATHY messages of which 13 percent were unusable. This gives an average of 24 usable bathythermographs per day.

There was some improvement in the number of reports received during December, compared with November; however, the lack of information and its decline is extremely noticeable during the holiday period at the end of December. For the month there was an average of 28 usable BATHYS per day.

It was noteworthy and gratifying to see that the input of data took a sharp upswing during January, 1966. The usable reports were up to an average of 50 per day in the Pacific area which, while still a meager number, indicates some response to stress of the importance of these observed data to the Fleet.

The distribution of the bathythermograph reports is shown in Figures 2, 3, 4, and 5. In addition, the geographic distribution of errors greater than 100 feet and less than 100 feet is shown in Figures 6 through 13.

Errors will appear in these data even though much care was taken to check them. The values of forecasted and analyzed mixed layer depth as read from the charts were estimated to the nearest 10 feet using linear interpolation between contours. It is realized that the actual field is not linear; however, it is felt that the user does, in fact, use the simplest method for interpolation. The charts used were on the 1:60,000,000 scale. It was not realized until the

data were almost completely analyzed that strip charts of a 1:30,000,000 scale could have been obtained. Had the 1:30,000,000 scale been used, it is possible that the values extracted from these charts could have been more accurate, but is believed this feature would not have caused a significant change in the results obtained.

To eliminate possible biasing of the results, the mixed layer depth as indicated by the BATHYS were obscured during the processing to render it impossible either to tend toward or away from the base value in those instances where the estimated values from the charts were ambiguous. This not only tended to eliminate biasing of the data, but also enhanced the speed with which the data could be recorded.

Mathematical errors are always present, but all results were rechecked to reduce and hopefully to eliminate this error source. No time error was considered in the verification procedure. It was assumed that all the bathythermographs were taken at the same time on the days indicated.

## 4. RESULTS AND DISCUSSIONS

As illustrated in the month of October, 1965, (Figure 14 and 15) 55 percent of the analyzed and 57 percent of the forecasted values were within ± 40 feet of the layer depth indicated by the bathythermographs. On the other hand, 11.6 percent of the values were outside the 100 foot error range. October showed the best results of the four months examined.

During November, 1965, (Figures 16 and 17) the results indicated a slightly increased number of errors outside the acceptable 40-foot range. For this period 51 percent of the analyzed and 50 percent of the forecasted values lay within the acceptable (± 40 foot) range.

In December the results showed a very abrupt change and the resulting errors within a specified limit drop sharply showing only 39 percent of the analyzed (Figure 18) and 38 percent of the forecasted values (Figure 19) within the set limit. At the same time the number of errors outside of 100 feet increases to 30 percent for the analyzed and 25 percent for the forecasted layer depth.

The final month examined, January, 1966, showed the largest percentage of errors outside the 100-foot range and the smallest percentage within the 40-foot range (Figures 20 and 21).

When the data for all four months are brought together and percentages are figured for the total data used, 42 percent of the forecasted/analyzed values are found within the excellent (± 40-foot) range, while 26 percent of the errors were in the area of poor (greater than ± 100 feet) predictions. (Figures 22 and 23).

In an effort to discover if the errors were consistent in location, the monthly geographic distribution of the BATHYS was

plotted along with the positive and negative distribution of the errors greater than ± 100 feet (Figures 2 through 13). Only the forecasted values were utilized for this procedure. It appears that during the entire period the distribution of negative errors was concentrated between 30-40 degrees North and 120-140 degrees West in the Eastern Pacific and appears to be random in the Western Pacific. This random pattern in the Western Pacific was accompanied by an increase in the number of errors during the latter part of the period observed. The positive error distribution was the reverse of this with randomness apparent in the Eastern Pacific and concentration in the South China Sea and Philippine Sea areas.

The concentration of negative errors in the Eastern Pacific area could be due partly to cold subsurface advection in that particular area and to surface heating and light winds. A possible cause could be the established halocline in the area as described by Tully in reference 1. This halocline would prohibit the mixed layer from increasing. Although this error concentration is not located totally in the proper area for the occurence of a halocline as described by Tully, it is intersected by the boundary between two distinctly different regions and, therefore, influenced by the dominant feature of both. This boundary area would have the effect of causing a shallow mixed layer which would result in the negative errors found. The concentration of negative errors is fairly consistent in number and location throughout the entire period of the investigation.

The positive error concentration in the Western Pacific is influenced by the convective stirring that occurs due to density

differences brought about by the excessive evaporation, the influence of the Kuroshio current, the heat losses that occur during the cooling seasons, and the accumulation of the surface waters in this area due to westward surface transport by the prevailing currents. The concentration of these positive errors is also fairly constant geographically, shifting only as the concentration of data shifts. The number of these errors, however, increases during the month of December, 1965. This is the month that a major change in the computation program was made at Fleet Numerical Weather Facility. The change re-established the land-sea boundary in the computer program, allowing more detail to be shown close to shore. It also updated the climatological information for the Western Pacific area. The effects of this change are readily apparent in the positive and negative error distribution for the latter two months of the verification period. Not only does the number of positive errors increase, but even more noticeable is the increase in the number of negative errors, as well as their sudden appearance in the Western Pacific. In October and November, 1965, there were only 21 negative errors reported in the entire area. This is three percent of the total observations for the Western Pacific. This increased to 68 negative errors or 16 percent of the observations during December, 1965, and to 92 negative errors, 10 percent of the observations, for January, 1966.

The abrupt change which occurred can only be attributed to the program change since no known dramatic oceanographic changes occurred for that time period in that part of the ocean.

The distribution of errors as shown in Figures 6 through 13 must

be viewed carefully. In many instances, although the percentages are high, the number of observations are low. In those areas where relatively large numbers of observations occur, the information can be considered more reliable.

Figure 24 is a distribution of the errors greater than + 100 feet. This particular distribution was analyzed only for the forecasted values for January, 1966. It is assumed that the positive and negative errors of greater than 100 feet for all months will be similarly distributed.

Three areas of the Pacific were chosen to conduct a study to investigate the variation of the error with time and space. The locations selected were the three Ocean Station Vessel sites because of their reporting consistency. These sites were considered to represent three different ocean areas. To arrive at a single error value to plot, the arithmetic mean was computed for the stations that reported a BATHY more than one per day. This eliminated the daily variation and allowed an investigation of a larger time period (i.e. weekly, monthly, etc.). The absolute mean was also calculated. In only 31 cases was this different from the arithmetic mean with a maximum variation of 175 feet. It is not evident from visual inspection of Figures 25, 26, 27, and 28 that a systematic time variation is present. It is noticeable in the month of October (Figure 25) that for the period between 15-31 October there were small errors in the observation at stations "P" and "N". The weather maps for these dates were checked to see if this was the result of an anomalous calm over the Eastern Pacific during this period, but it is not apparent from the weather charts that this was

the case. This small error feature continued to be evident from 1-14 November, but this time the small differences occurred between stations "P" and "V". Throughout the remainder of the time, random large variations occur at all stations with no perceptable frequency.

Tabulation of the errors at the three locations revealed that on selected days large differences in the errors occurred. In an effort to account for the error difference, all of the BATHYS were plotted for the days in October that demonstrated extreme errors. The BATHY traces are shown in Figures 29, 30 and 31. Previously, large errors occurring at the same station were eliminated under the assumption that they were due to instrument malfunction. It is not evident from the figures that this is the circumstance. In each instance the BATHY trace appears to be a valid one. If instrument error is ruled out, as it has been for these selected days, the large differences do occur and can be accounted for in part by internal waves, advection, and extreme convective mixing occurring in a short period of time.

Apparently, from the BATHY traces, the prediction system shows its largest negative error if there is no well defined layer depth. This is illustrated in the BATHYS for 5 October and 17 October (Figures 29 and 30) where a negative temperature gradient was present from the surface to the bottom of the trace. In both cases the actual layer depth was zero while the model forecasted a much deeper layer. This study was extended to all zero layer depths at Ocean Station Vessels "P", "N", and "V" for the four months. In every instance but two, an observed zero layer depth always resulted

in a large negative error.

As a result of preliminary analysis of the data, a separate study was undertaken to observe the effect in the analyzed and forecasted mixed layer depth as a result of passing the BATHY information through the analyzed field a varying number of times.

The separate study was seeking to determine if additional or fewer passes by the computer for BATHY comparison and adjustment purposes would cause a marked increase in the accuracy of the forecast/analysis. For this study, a limited and different collection of data was utilized, including some data from the Atlantic Ocean area. By referring to the graphed results (Figures 32 through 35) it is evident that three passes, the standard procedure at present, does not appear to achieve the optimum accuracy. It would appear from this limited test on only one day's data that five passes would result in the best utilization of these observed data under the system being used at present. This test suggests that any more than five passes is associated with a spread and increase of errors. This is strange because the program should, if enough passes were made, bring all observed data to within ± 30 feet of the BATHY value.

## 5. CONCLUSIONS

From the data analyzed, only the months of October and November, 1965, showed results that are acceptable or within the excellent catagory. The overall data yields 42 percent acceptable forecasts.

The $\pm$ 100 foot horizontal error distribution for October and November, 1965, was acceptable and as realistic as can normally be expected. The same distribution for the latter two months of the period is unacceptable. This large deviation is due to a major change that occurred in the program. It is evident that this change took place without the benifit of extensive verification; the change appears to be detrimental to the overall product. It is suggested that prior to any major change an extensive verification program should be conducted and that changes made should at least in part hinge on the results of the verification.

The concentration of positive errors in the Western Pacific may be due to many factors, some of which could be approximated in the mixed layer depth program (i.e. transport of surface waters to the west) to reduce this error to more acceptable results.

The small errors that occurred in October, 1965, at stations "P" and "N" are not a result of weather phemomena but could be caused by strong convective stirring at both stations simultaneously. There is no connection between the small errors at stations "P" and "V" during the first part of November, 1965.

The large errors that appear in the time study are not attributed to instrumentation, but to the inability of the numerical model to handle a zero layer depth situation. While it is not possible to

describe accurately the effects of advection it can be approximated and considered. The fact that each large negative error was associated with an observed zero layer depth serves to illustrate this quite clearly.

The present system of three passes of the observed data is not optimum. A more extensive project should be undertaken to determine the optimum number of passes to obtain maximum error reduction.

It is apparent that changes occur rapidly at Fleet Numerical Weather Facility. These changes come about as a result of theoretical evaluation of the relationships between the atmosphere and the ocean. There is no extensive program that verifies the product and makes changes as a result of this verification.

Although much remains to be done in attaining perfection in analyzing and forecasting oceanographic parameters by numerical methods, the process used by Fleet Numerical Weather Facility and described here is a step in the proper direction. It not only solves the time delay problem by providing up-to-date information, but is accurate to the extent that, used in conjunction with data obtained on the scene, it can provide an operationally useful forecast of the mixed layer depth.

The program in its present state cannot handle layer depths that exceed 600 feet. This tends to introduce erroneous information into the system that would result in a positive error in all cases. This is the more preferable side of the scale to be on from an operational standpoint. A positive value of the error results in a shorter detection range for the sonar equipment, thus, in effect,

increasing the protection over that expected. Under this criterion the operational accuracy is much different from the actual accuracy explained previously. Twenty percent of the time the forecasts would have an adverse effect on the operating forces.

## 6. RECOMMENDATIONS

It is suggested that a weighting system be applied to the grid points that surround a given BATHY report. There is no reason to believe that each point should be lowered the same amount, especially if the BATHY is not in the center of the grid square.

It would seem appropriate that a routine daily, or at least monthly, verification program be instituted to maintain a continuous check on the product and to provide information as the basis for program changes that will increase the accuracy of the system. This could be accomplished routinely on the computer.

An extensive investigation into the accuracy of the sea surface temperature, the sea and swell analysis, and the current analysis is recommended because these all affect the mixed layer depth which is the most important of the oceanographic products.

## 7. ACKNOWLEDGEMENTS

For their time and patience I wish to express my thanks to the personnel of Fleet Numerical Weather Facility who provided the data for this paper. Appreciation and gratitude is extended to Professor Glenn H. Jung for his excellent guidance and counselling throughout this project. My thanks also to my wife who endured gracefully throughout the period.

| MONTH | TOTAL NUMBER OF BATHYS REPORTED | NUMBER OF BATHYS USED IN ANALYSIS (A), FORECAST (F) VERIFICATION | PERCENT OF ERROR DUE TO ENCODING AND TRANSMISSION | PERCENT OF BATHYS IN ± 40 feet | PERCENT OF BATHYS IN GREATER THAN ± 100 feet |
|---|---|---|---|---|---|
| OCTOBER, 1965 | 954 | A-685<br>F-869 | 8.9% | A-55%<br>F-57% | A-11.6%<br>F-11.6% |
| NOVEMBER, 1965 | 840 | A-731<br>F-731 | 13.0% | A-51%<br>F-50% | A-17.6%<br>F-17.6% |
| DECEMBER, 1965 | 960 | A-862<br>F-862 | 10.2% | A-39%<br>F-39% | A-30.4%<br>F-25.0% |
| JANUARY, 1966 | 1892 | A-1462<br>F-1548 | 18.2% | A-33%<br>F-33% | A-30.8%<br>F-31.5% |
| TOTAL | 4646 | A-3740<br>F-4010 | 13.7% | A-42%<br>F-42% | A-24.6%<br>F-23.2% |

TABLE 1 TABULATION OF DATA

| BT No. | Oct | Lat | Long | MLD | SST | SST | FCST MLD | ANAL MLD | SST ERROR | FCST MLD ERROR | ANAL MLD ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 2 | 32.7 | 171.0 | 220 | 68.3 | 64.4 | 350 | 350 | | -130 | -130 |
| 15 | 2 | 24.5 | 131.6 | 220 | 73.0 | 73.4 | 310 | 300 | | -90 | -80 |
| 16 | 2 | 15.2 | 114.7 | 200 | 78.8 | 77.9 | 90 | 100 | | 110 | 100 |
| 17 | 2 | 32.4 | 142.7 | 520 | 66.0 | 65.3 | 400 | 370 | | 120 | 150 |
| 18 | 2 | 30.3 | 159.3 | 300 | 70.0 | 69.8 | 300 | 300 | | 0 | 0 |
| 19 | 2 | 15.3 | 112.7 | 240 | 78.2 | 77.9 | 140 | 160 | | 100 | 80 |
| 20 | 2 | 28.9 | 131.4 | 500 | 68.0 | 69.8 | 320 | 300 | | 180 | 200 |
| 21 | 1 | 50.0 | 145.0 | 420 | 41.7 | 42.6 | 310 | 310 | | 110 | 110 |
| 22 | 1 | 30.1 | 140.1 | 520 | 64.4 | 65.3 | 400 | 400 | | 120 | 120 |
| 23 | 1 | 32.2 | 117.2 | 140 | 61.0 | 61.7 | 150 | 150 | | -10 | -10 |
| 24 | 1 | 32.0 | 117.3 | 120 | 60.9 | 61.7 | 150 | 150 | | -30 | -30 |
| 25 | 1 | 32.5 | 117.9 | 150 | 60.5 | 61.7 | 150 | 150 | | 0 | 0 |
| 26 | 1 | 30.0 | 133.9 | 480 | 65.3 | 62.6 | 400 | 350 | | 80 | 130 |

FIGURE 1 SAMPLE DATA COLLECTION FORM

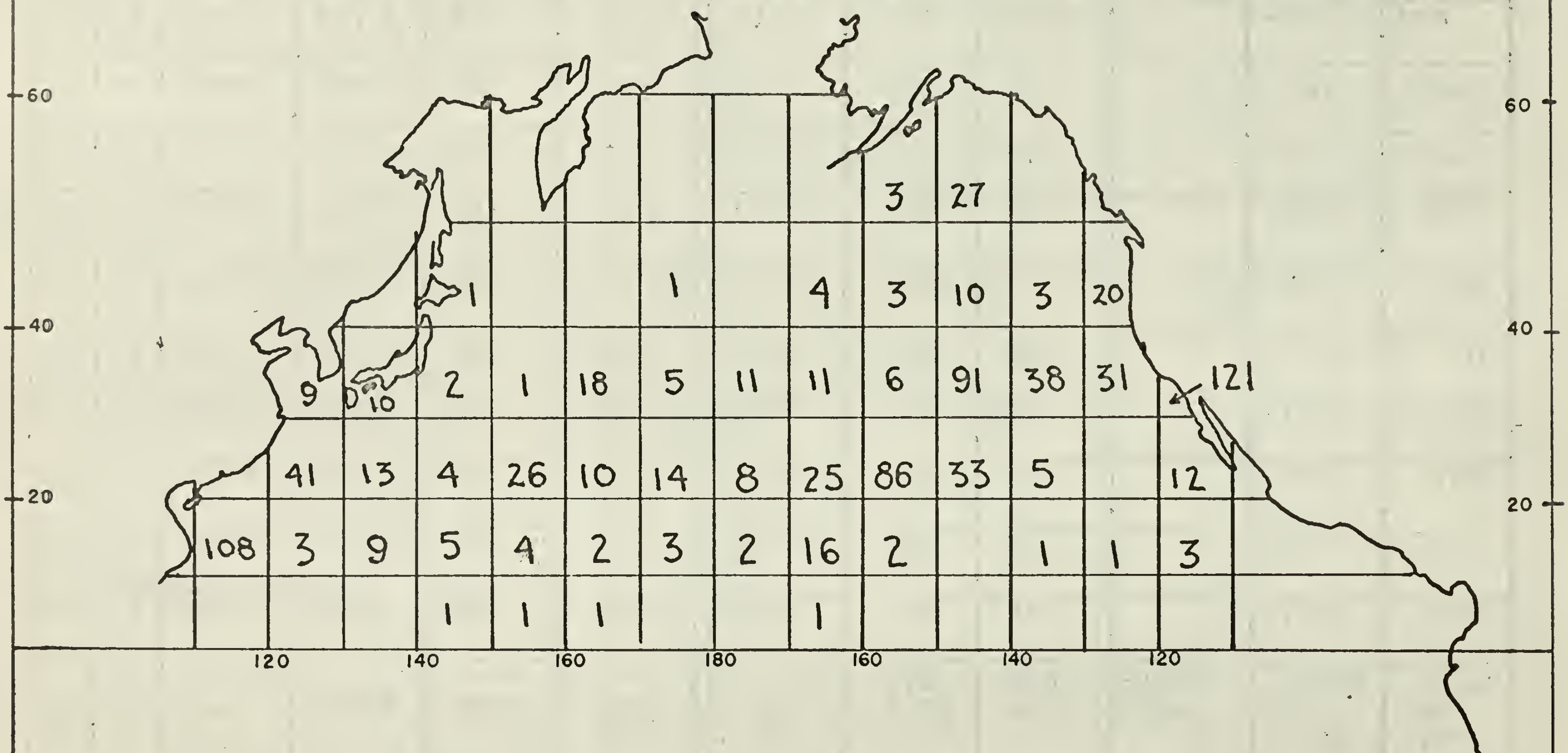


FIGURE 2 DISTRIBUTION OF BATHYS FOR OCTOBER 1965

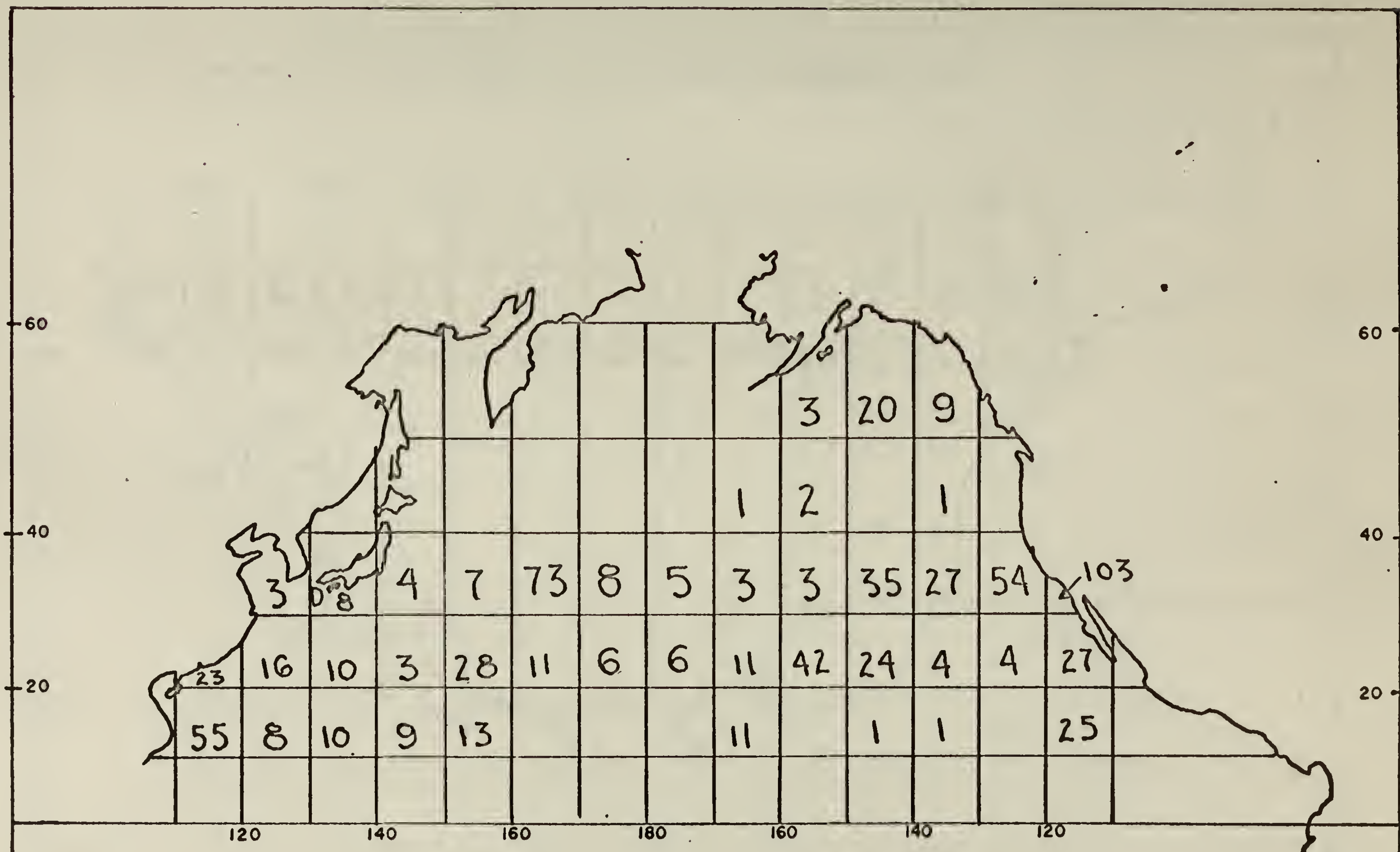


FIGURE 3 DISTRIBUTION OF BATHYS FOR NOVEMBER 1965

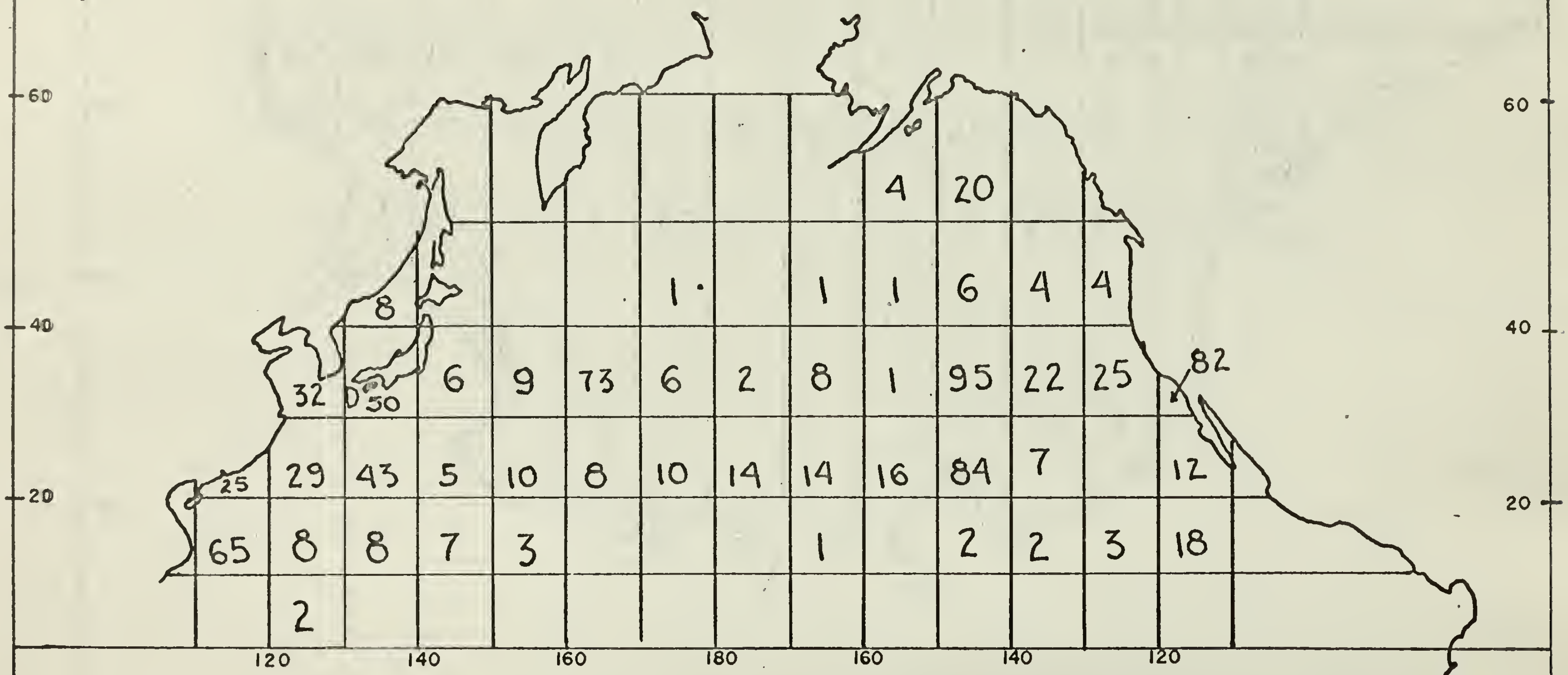


FIGURE 4 DISTRIBUTION OF BATHYS FOR DECEMBER 1965

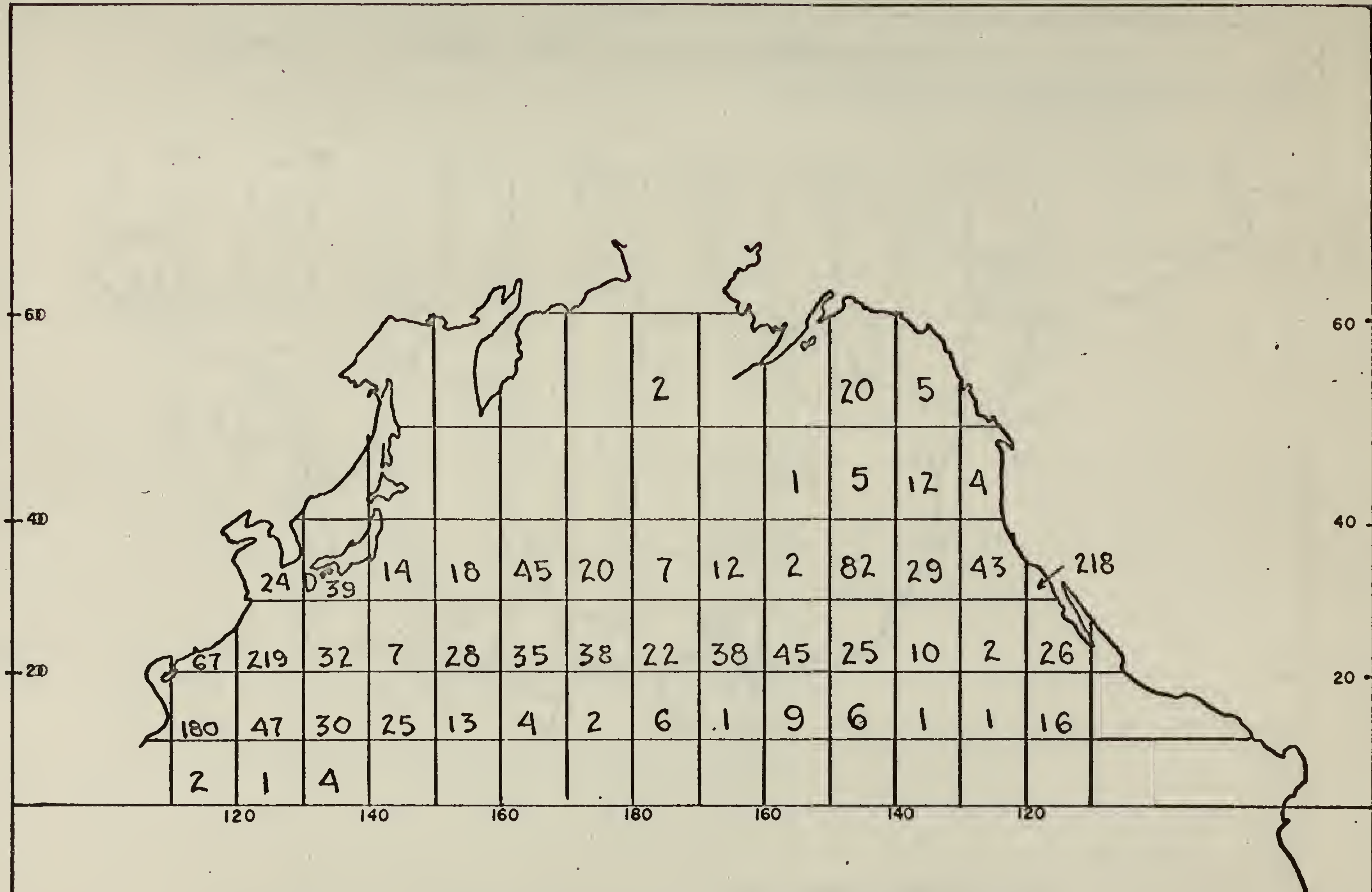


FIGURE 5 DISTRIBUTION OF BATHYS FOR JANUARY 1966

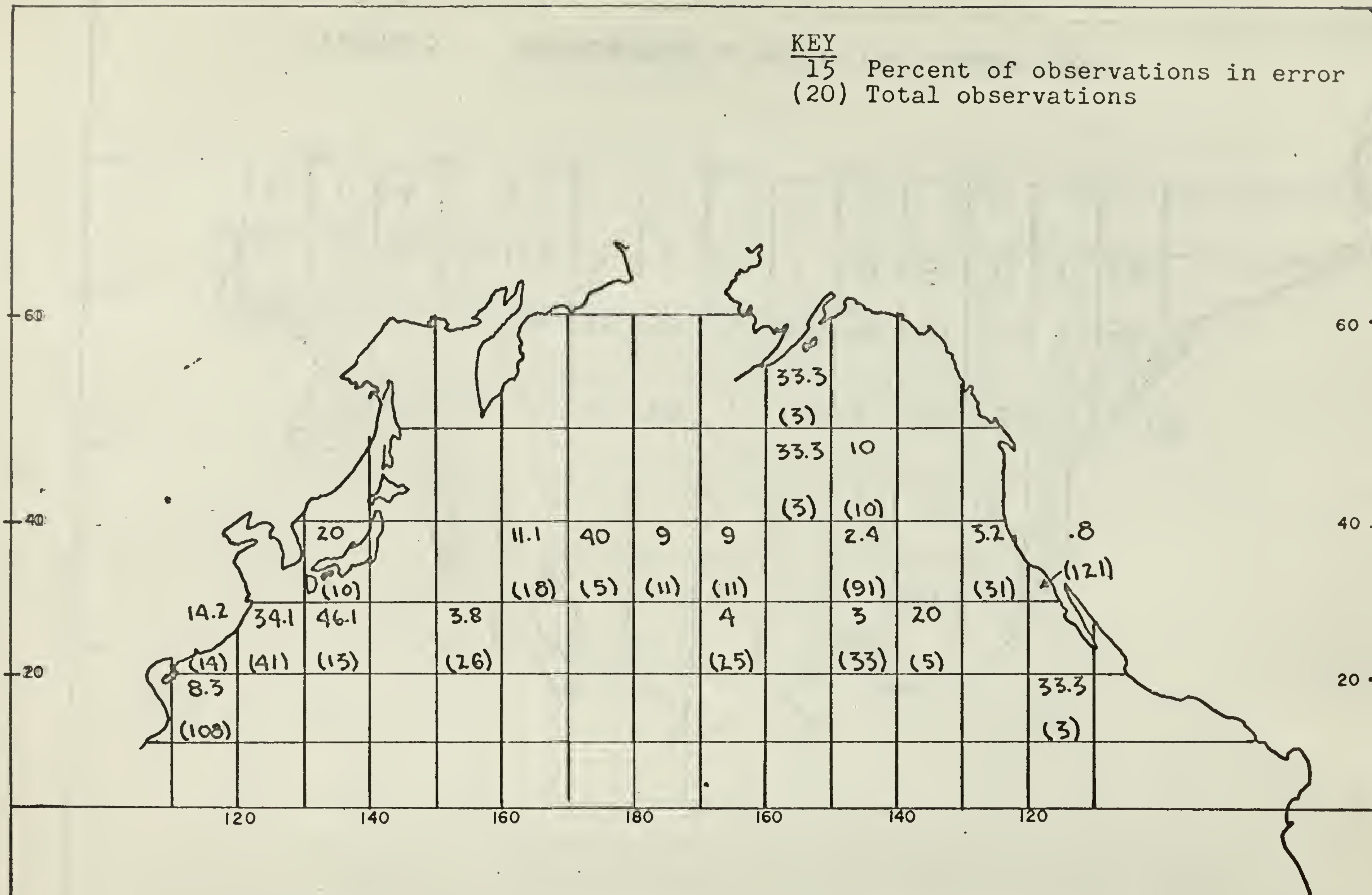


FIGURE 6 POSITIVE ERROR DISTRIBUTION (OCTOBER 1965)

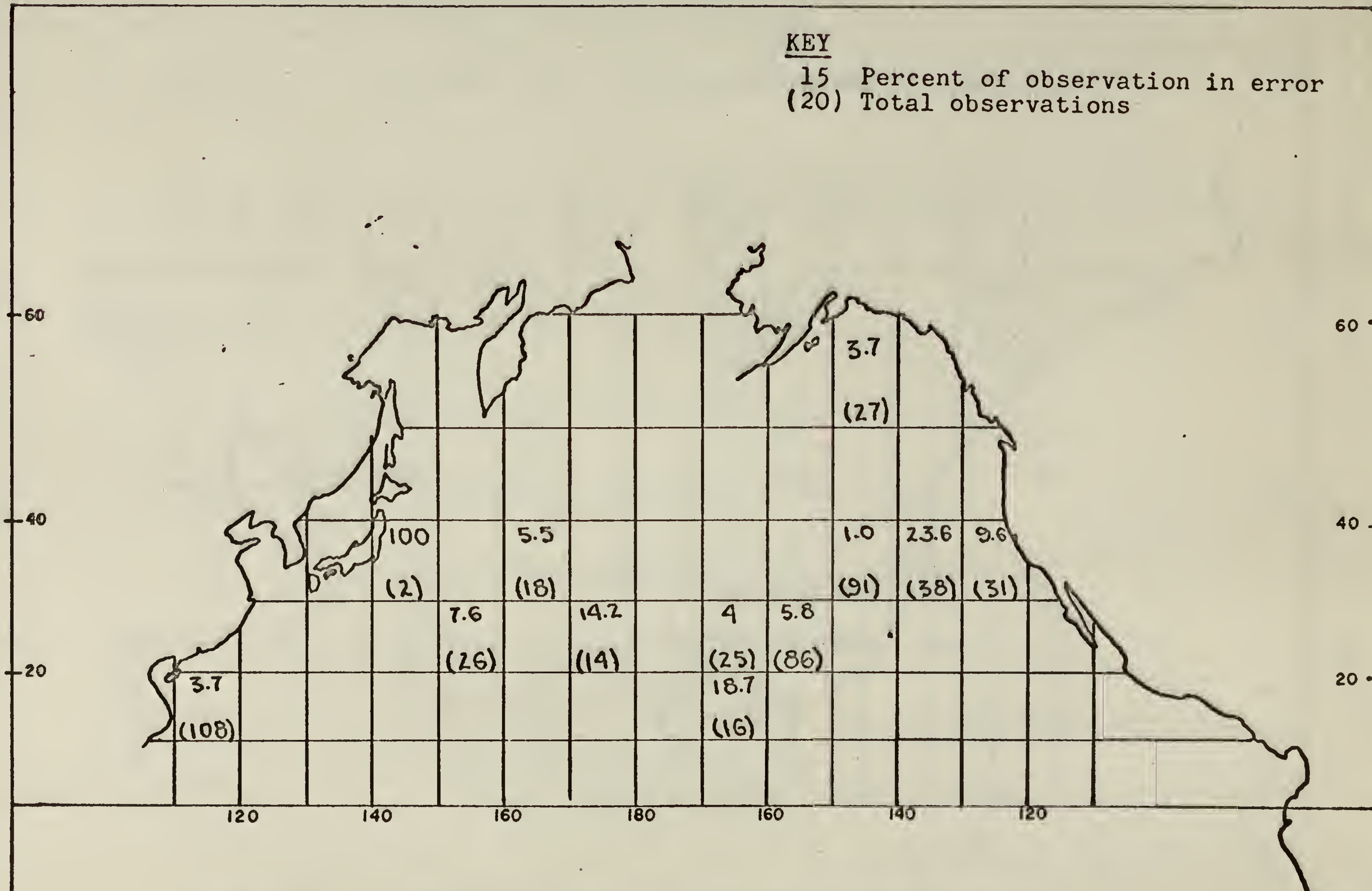


FIGURE 7 NEGATIVE ERROR DISTRIBUTION (OCTOBER 1965)

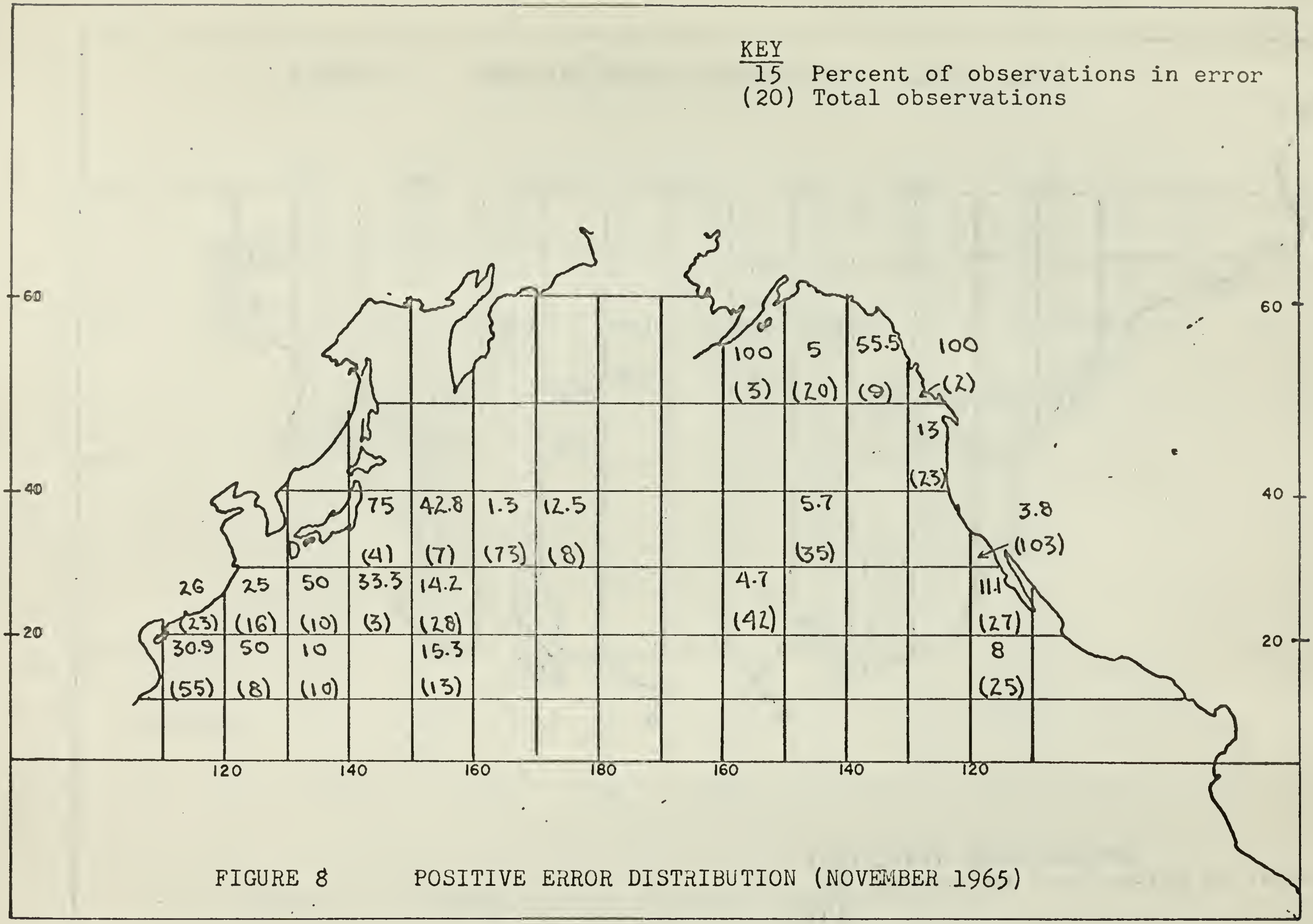


FIGURE 8 POSITIVE ERROR DISTRIBUTION (NOVEMBER 1965)

KEY
15 Percent of observation in error
(20) Total observations

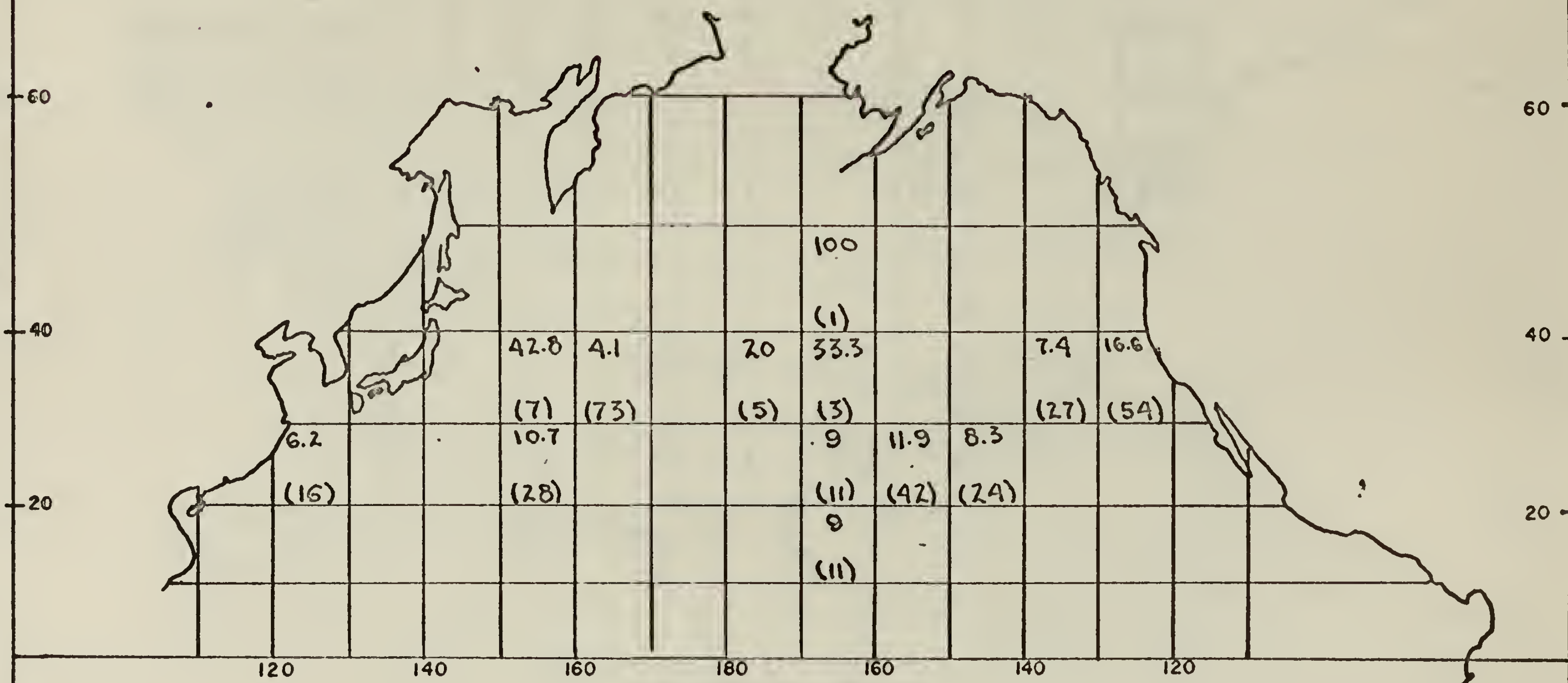


FIGURE 9 NEGATIVE ERROR DISTRIBUTION (NOVEMBER 1965)

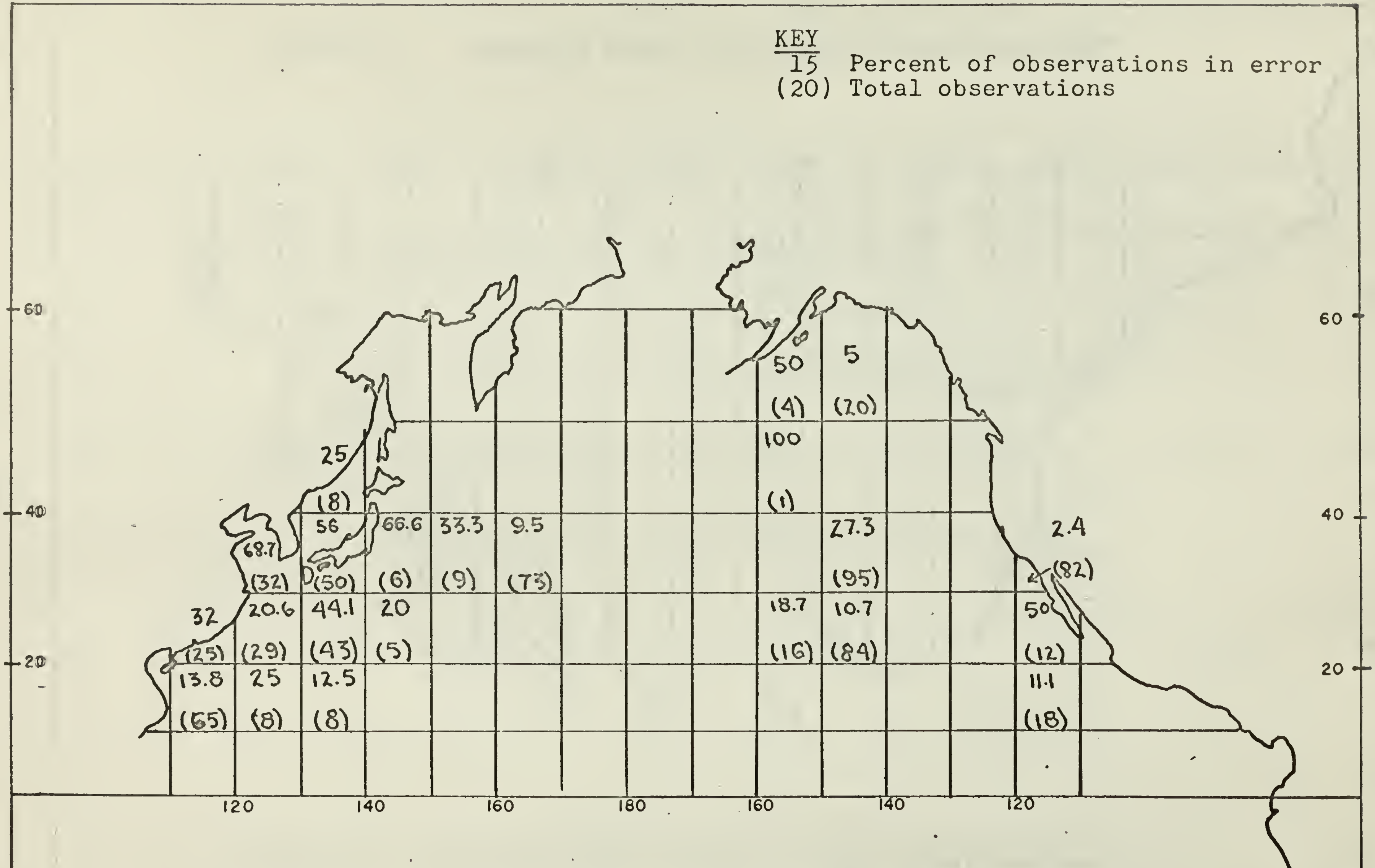


FIGURE 10 POSITIVE ERROR DISTRIBUTION (DECEMBER 1965)

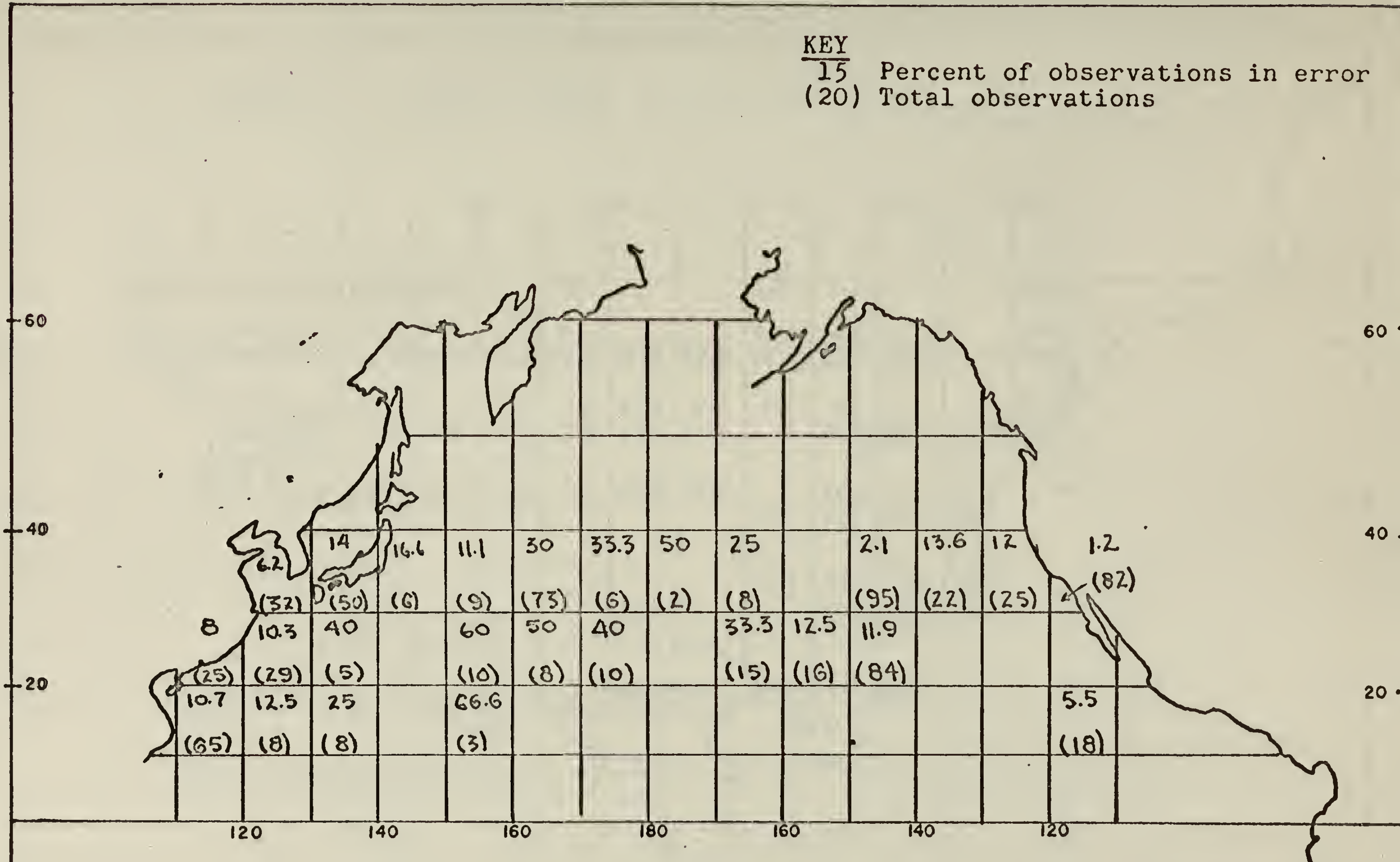


FIGURE 11 NEGATIVE ERROR DISTRIBUTION (DECEMBER 1965)

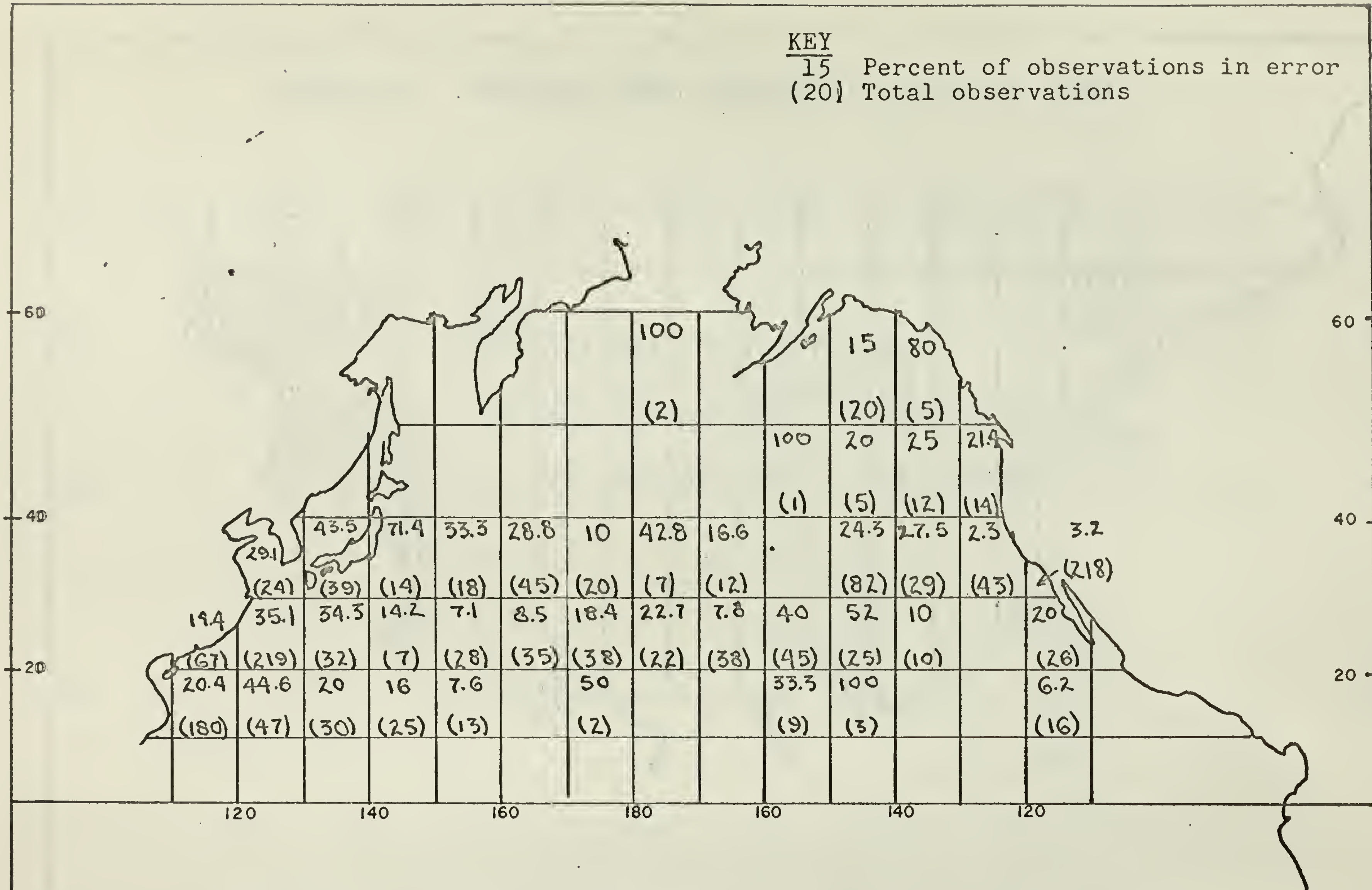


FIGURE 12 POSITIVE ERROR DISTRIBUTION (JANUARY 1966)

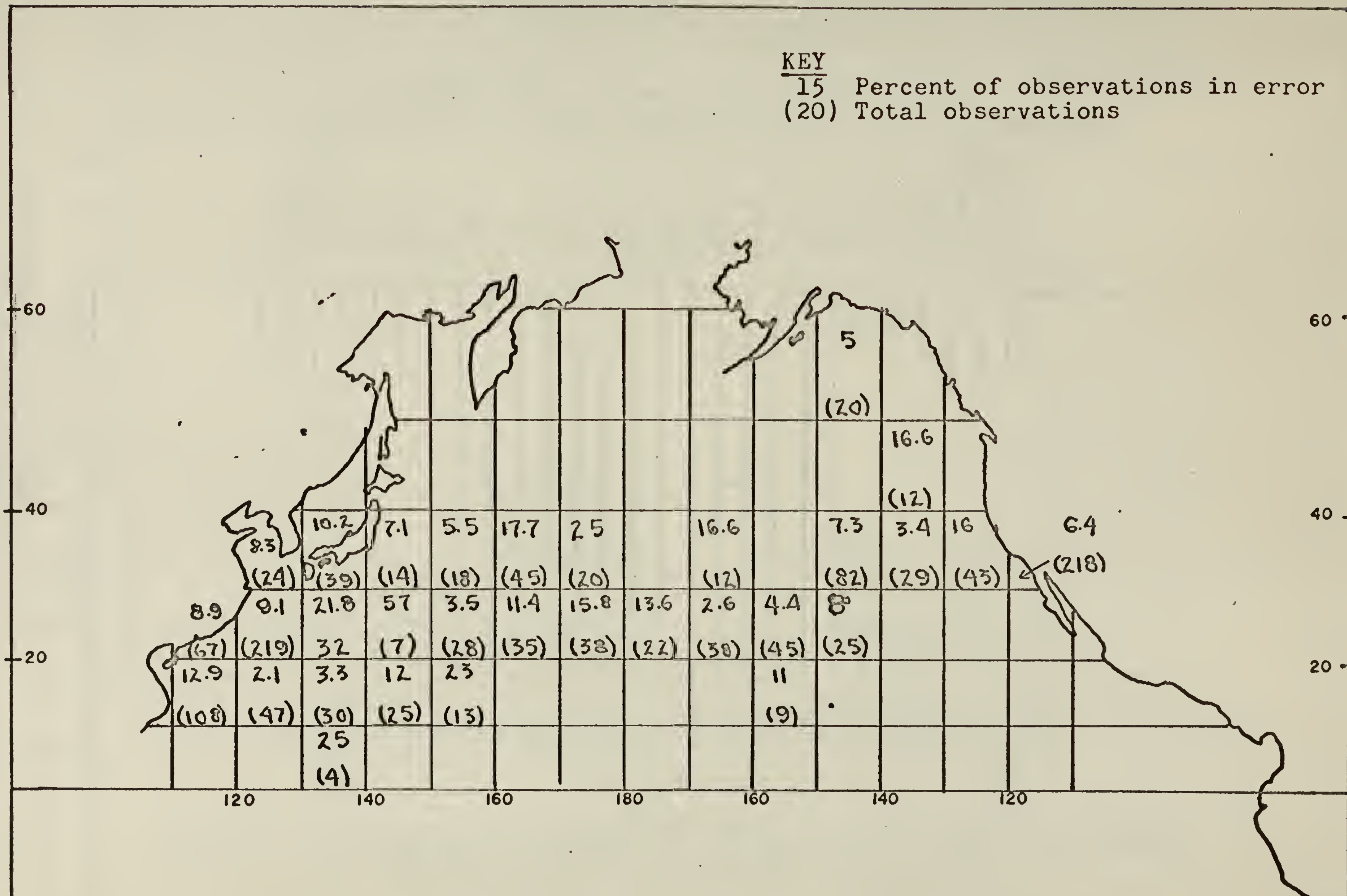


FIGURE 13 NEGATIVE ERROR DISTRIBUTION ( JANUARY 1966 )

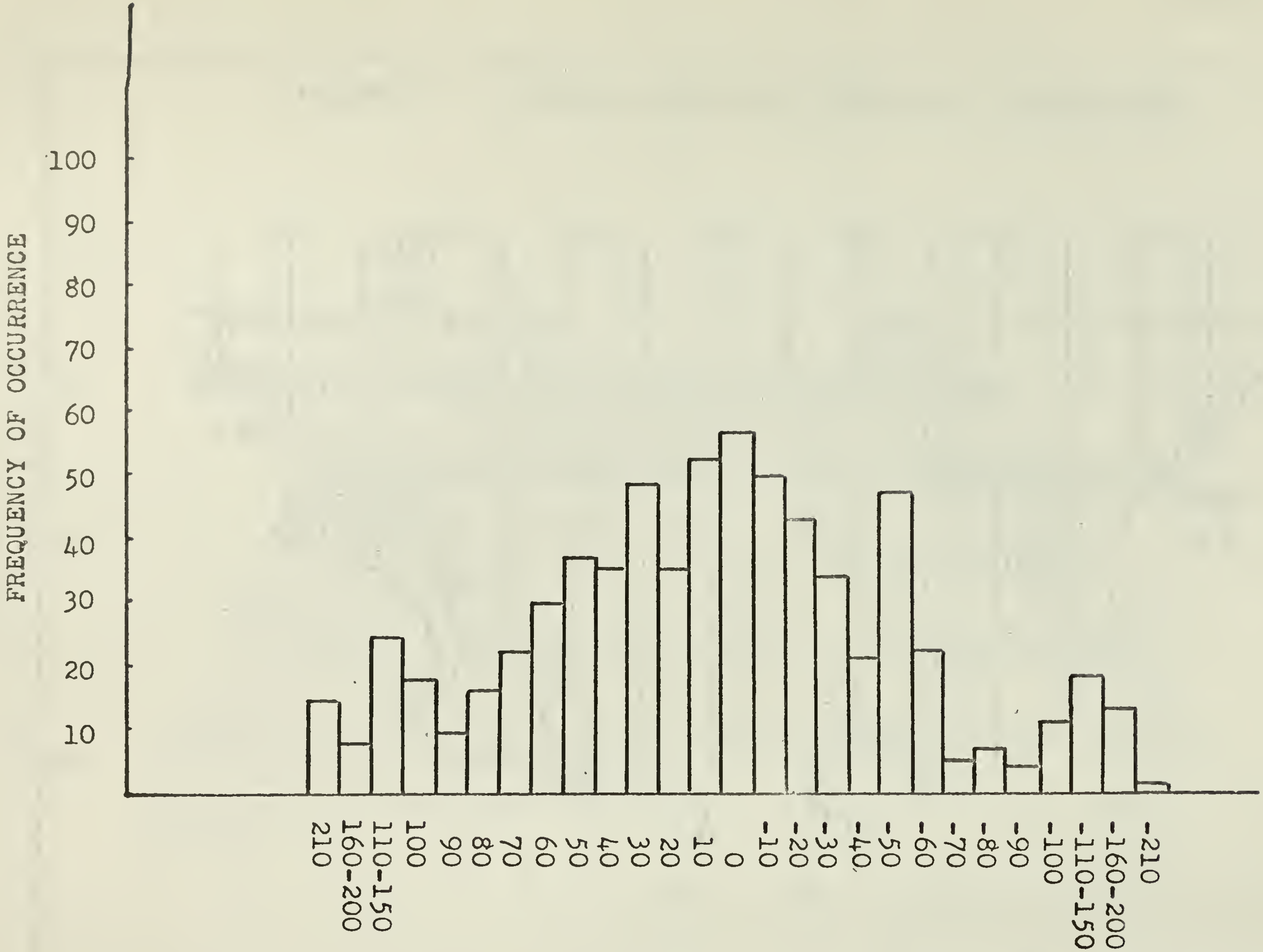


FIGURE 14 DISTRIBUTION OF ERRORS FOR THE ANALYZED MIXED LAYER DEPTH
OCTOBER 1965 (Based on 685 observations)

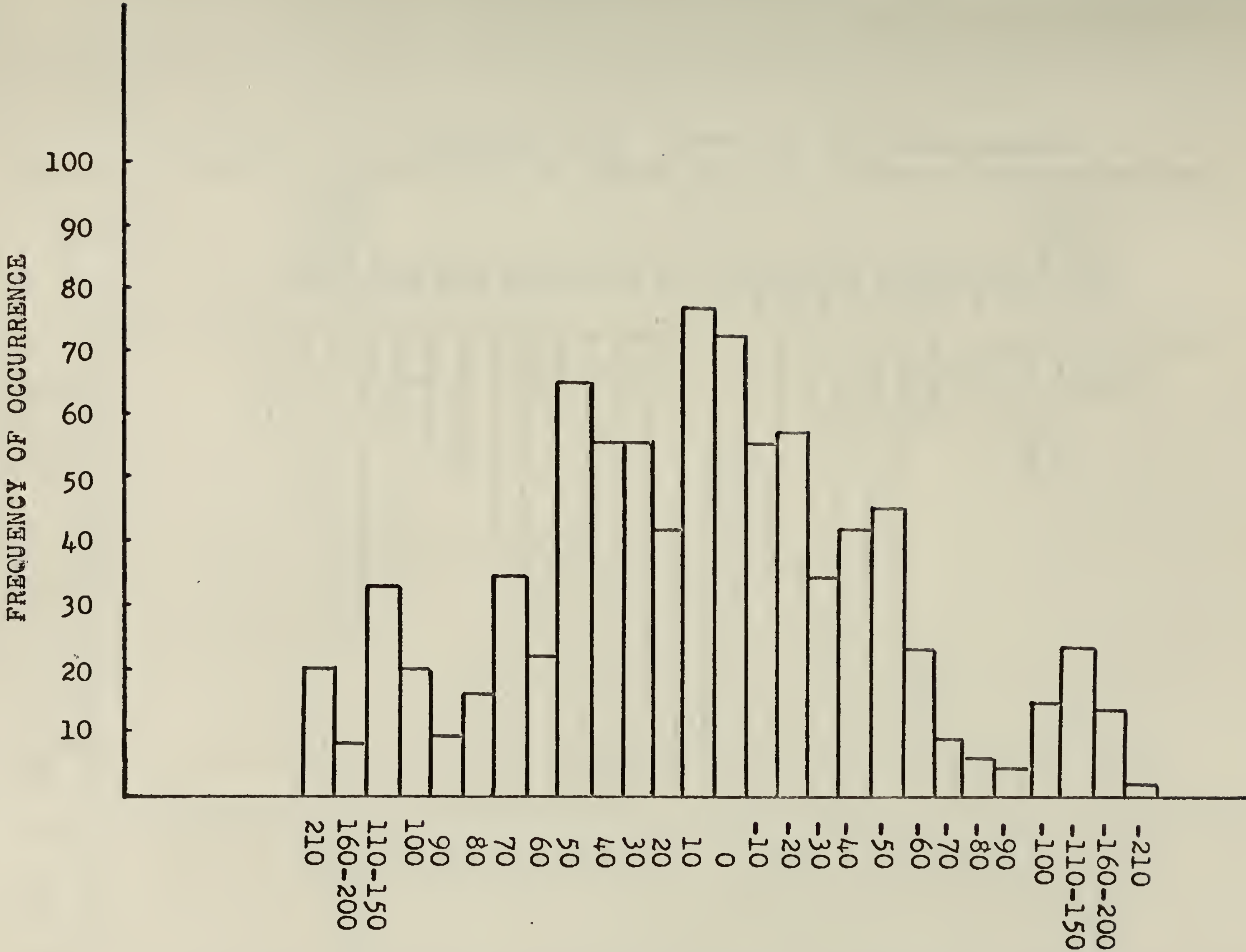


FIGURE15 DISTRIBUTION OF ERRORS FOR THE FORECASTED MIXED LAYER DEPTH
OCTOBER 1965 (Based on 869 observations)

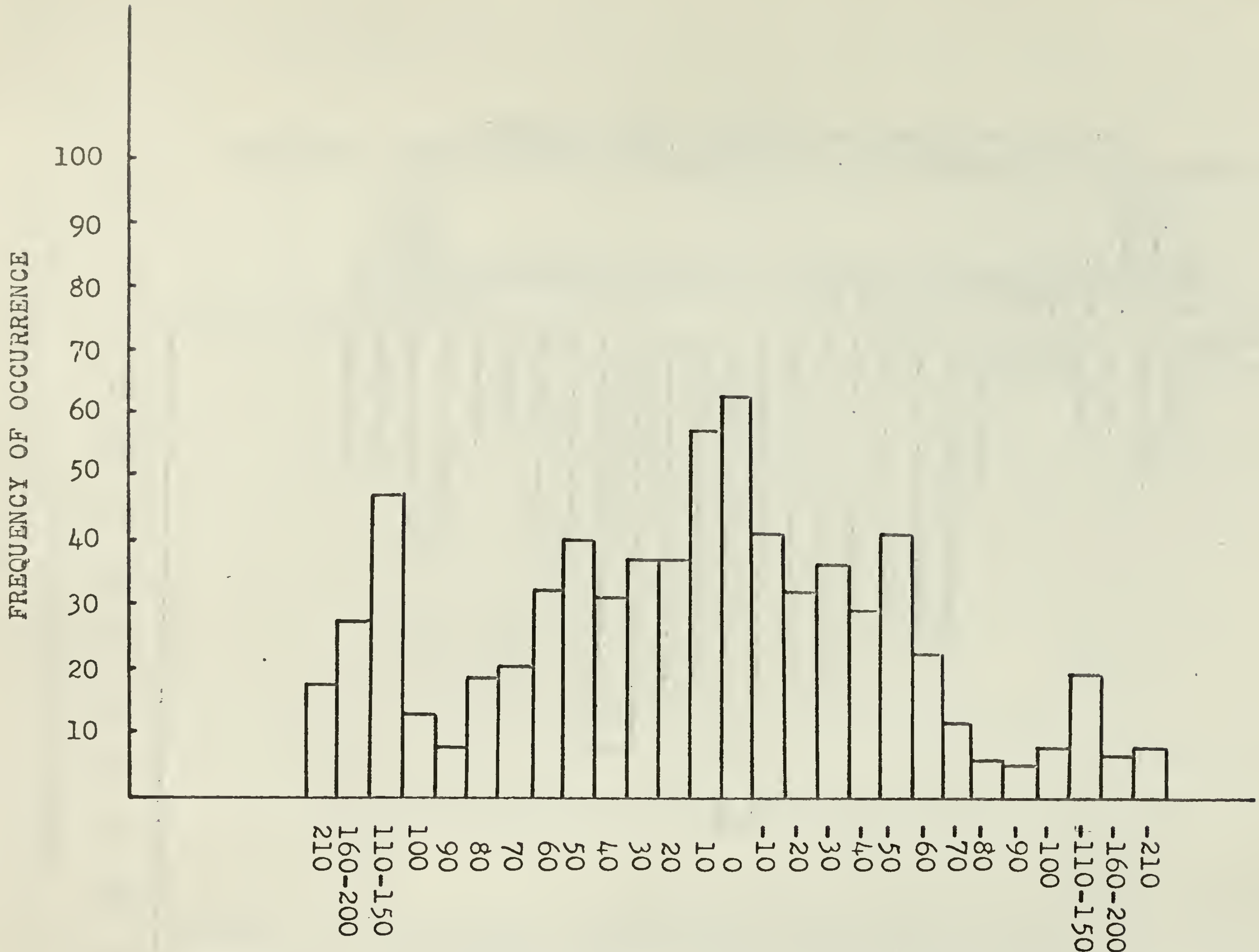


FIGURE 16 DISTRIBUTION OF ERRORS FOR THE ANALYZED MIXED LAYER DEPTH NOVEMBER 1965 (Based on 731 observations)

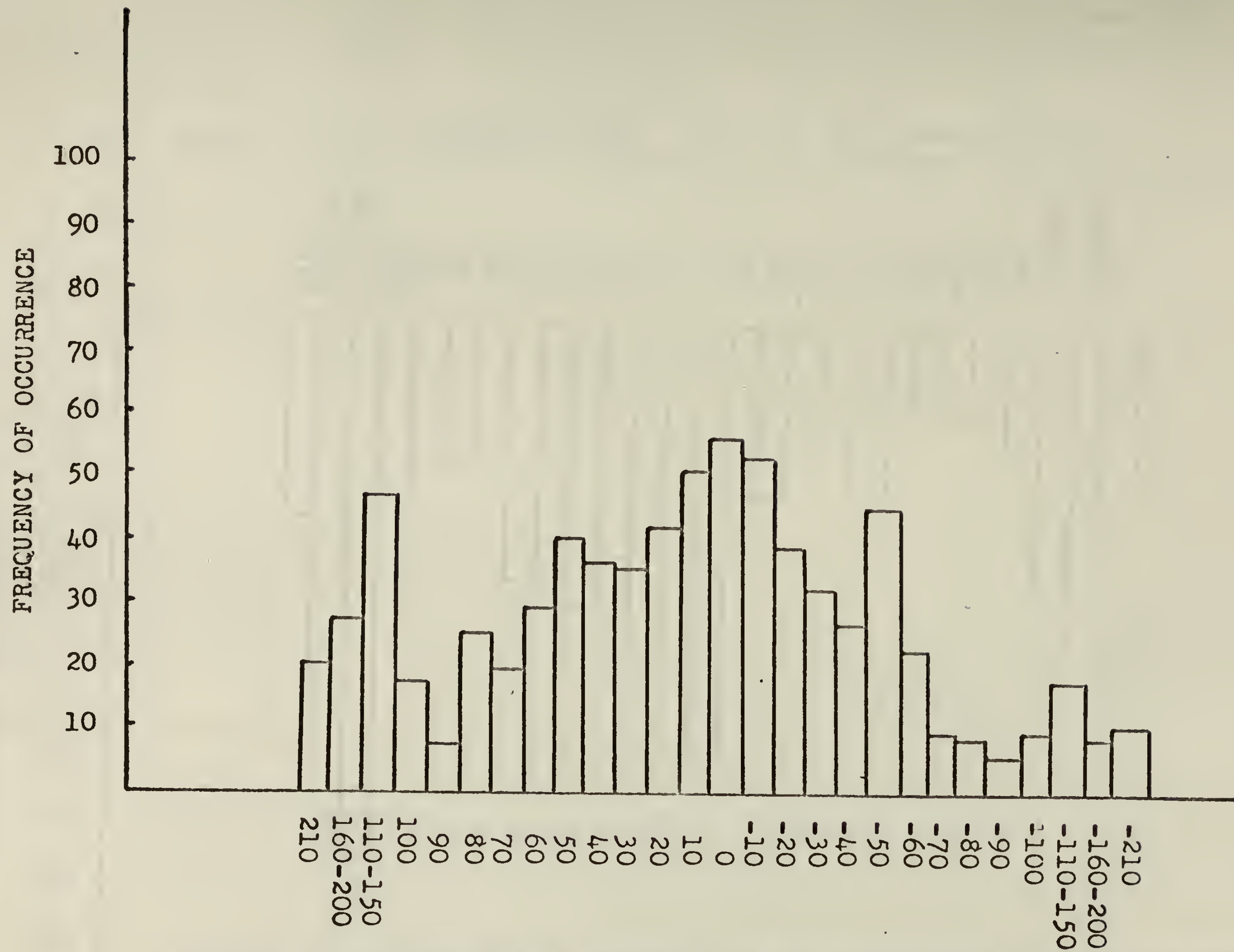


FIGURE 17 DISTRIBUTION OF ERRORS FOR THE FORECASTED MIXED LAYER DEPTH
NOVEMBER 1965 (Based on 731 observations)

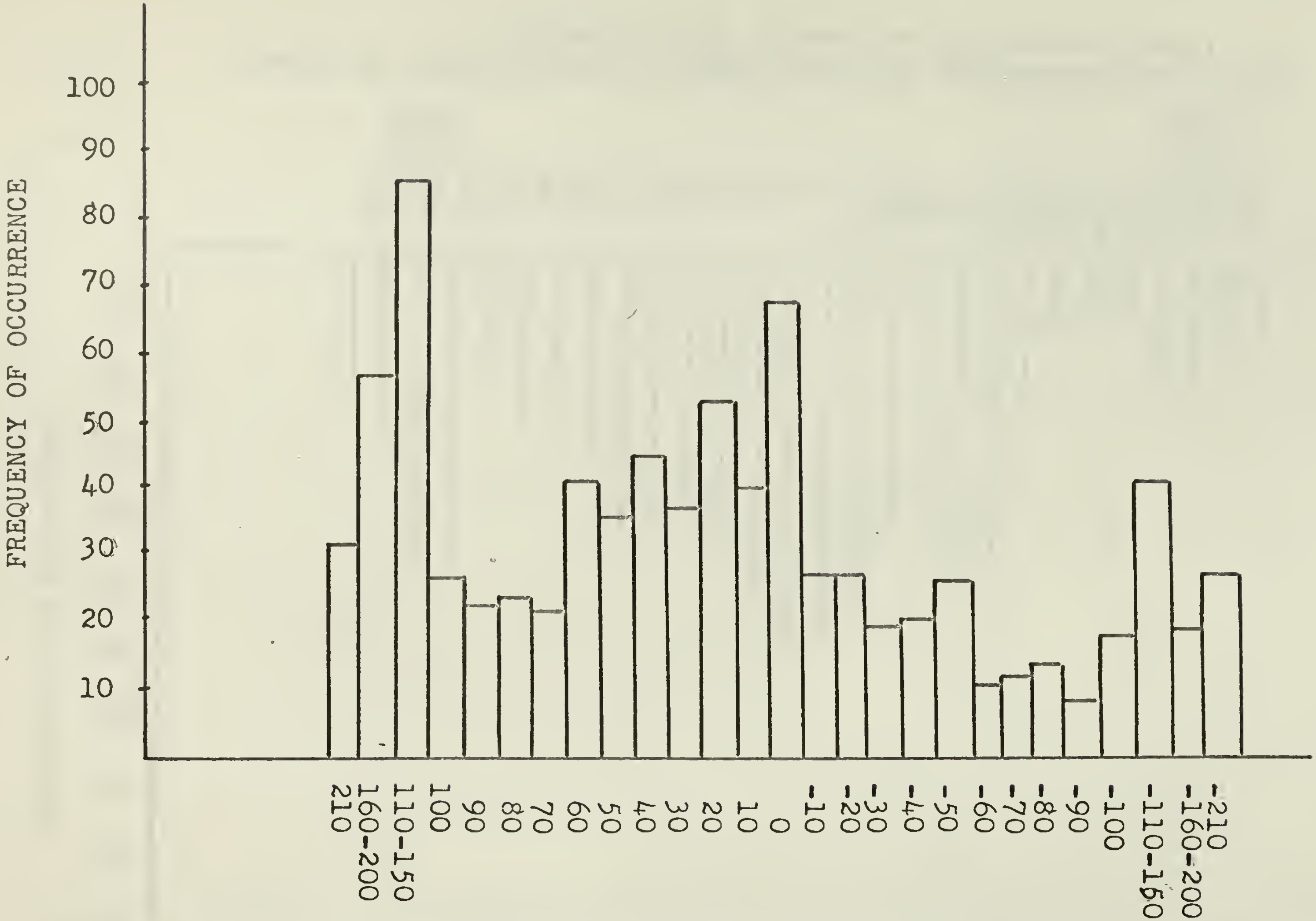


FIGURE 18 DISTRIBUTION OF ERRORS FOR THE ANALYZED MIXED LAYER DEPTH
DECEMBER 1965 (Based on 862 observations)

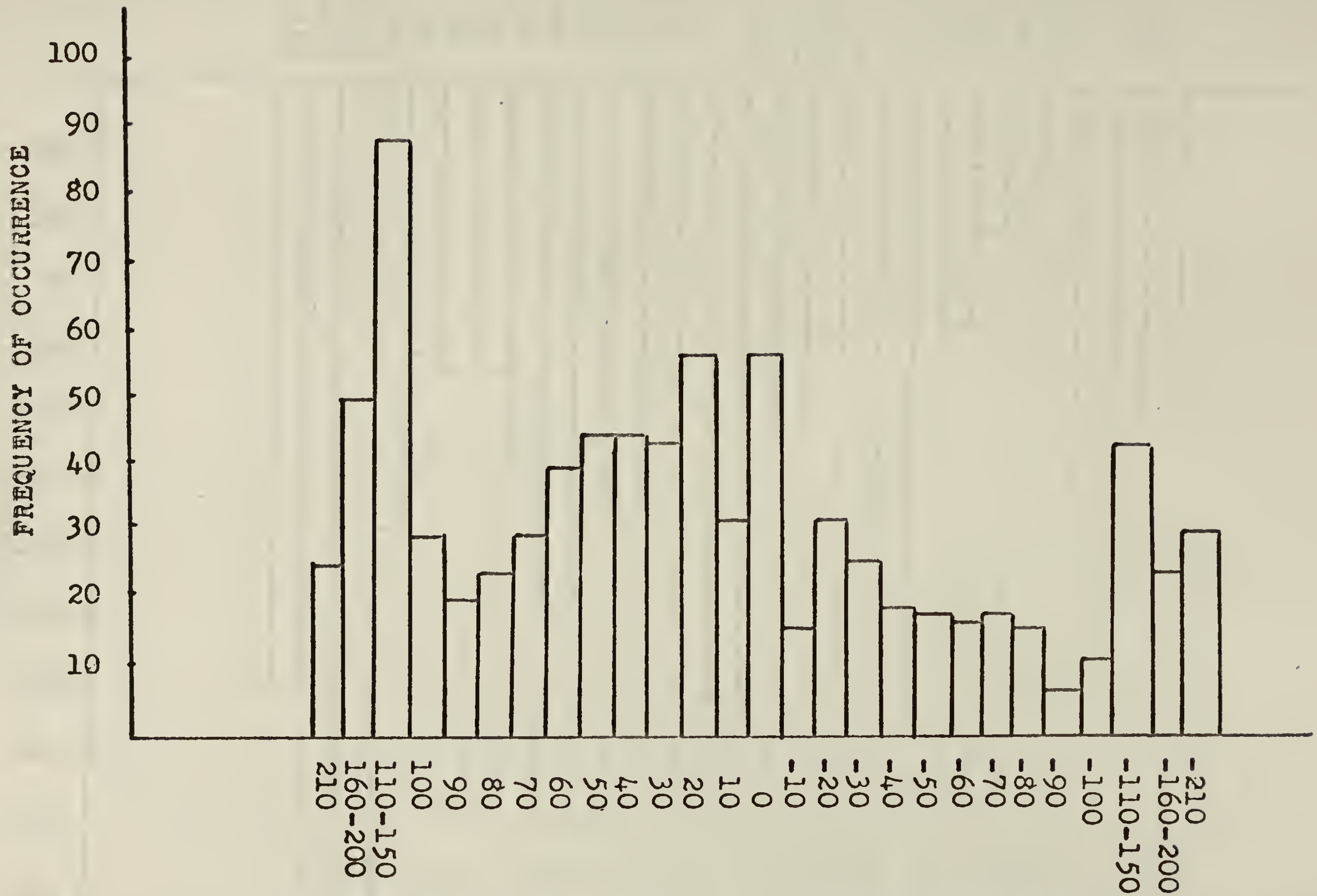


FIGURE 19 DISTRIBUTION OF ERRORS FOR THE FORECASTED MIXED LAYER DEPTH DECEMBER 1965 (Based on 863 observations)

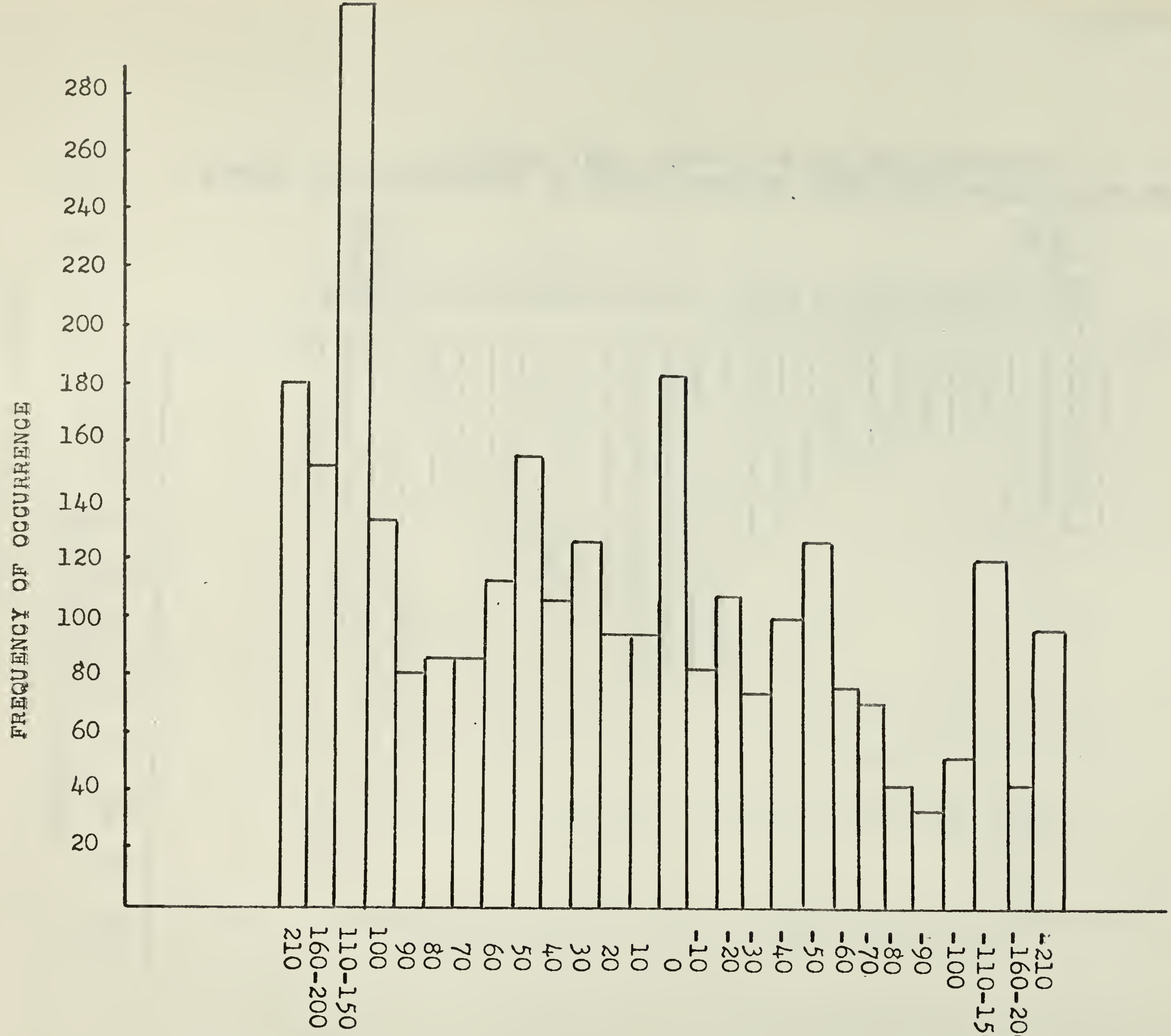


FIGURE 20 DISTRIBUTION OF ERRORS FOR THE ANALYZED MIXED LAYER DEPTH
JANUARY 1966 (Based on 1462 observations)

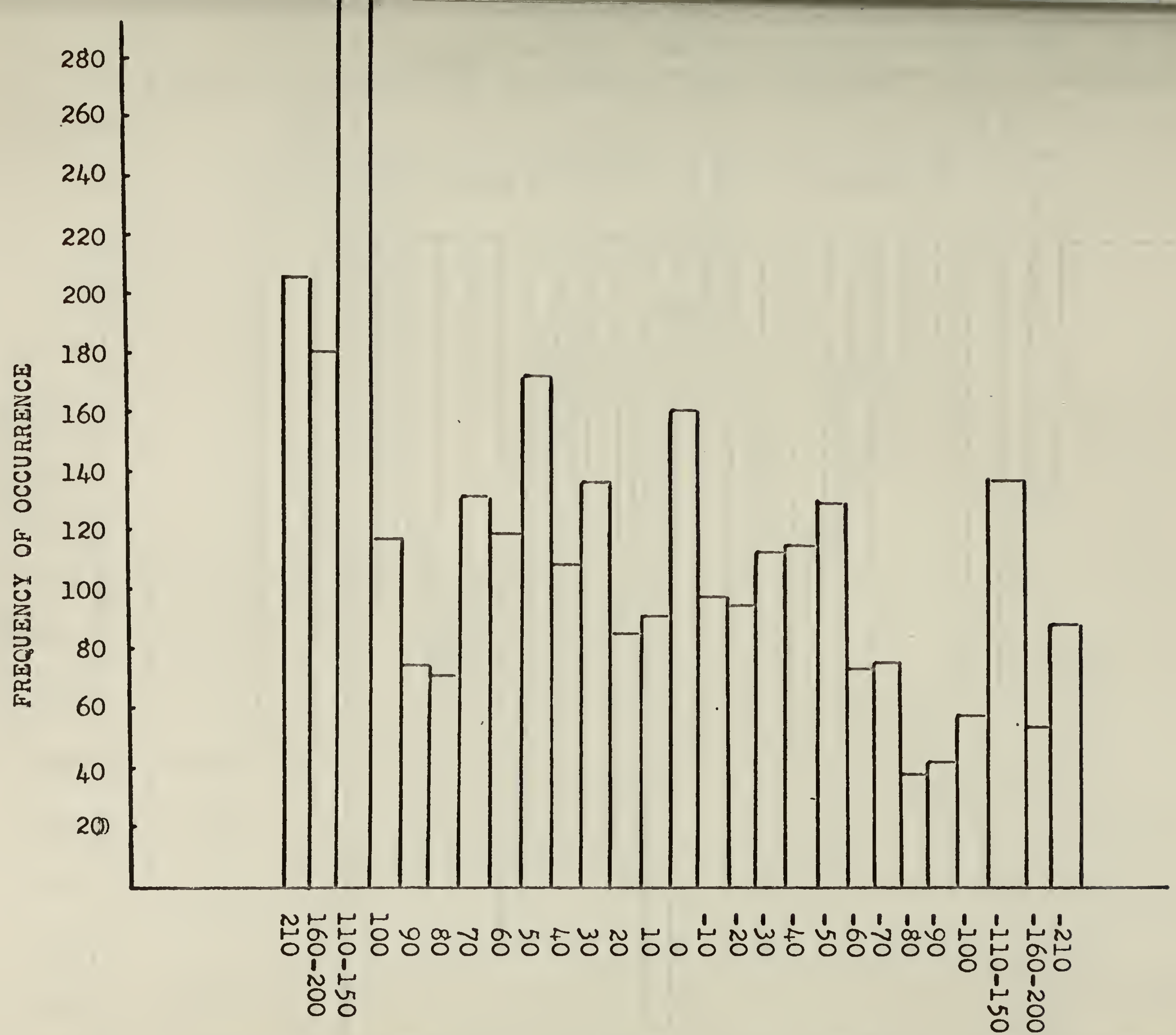


FIGURE 21 DISTRIBUTION OF ERRORS FOR THE FORECASTED MIXED LAYER DEPTH
JANUARY 1966 (Based on 1548 observations)

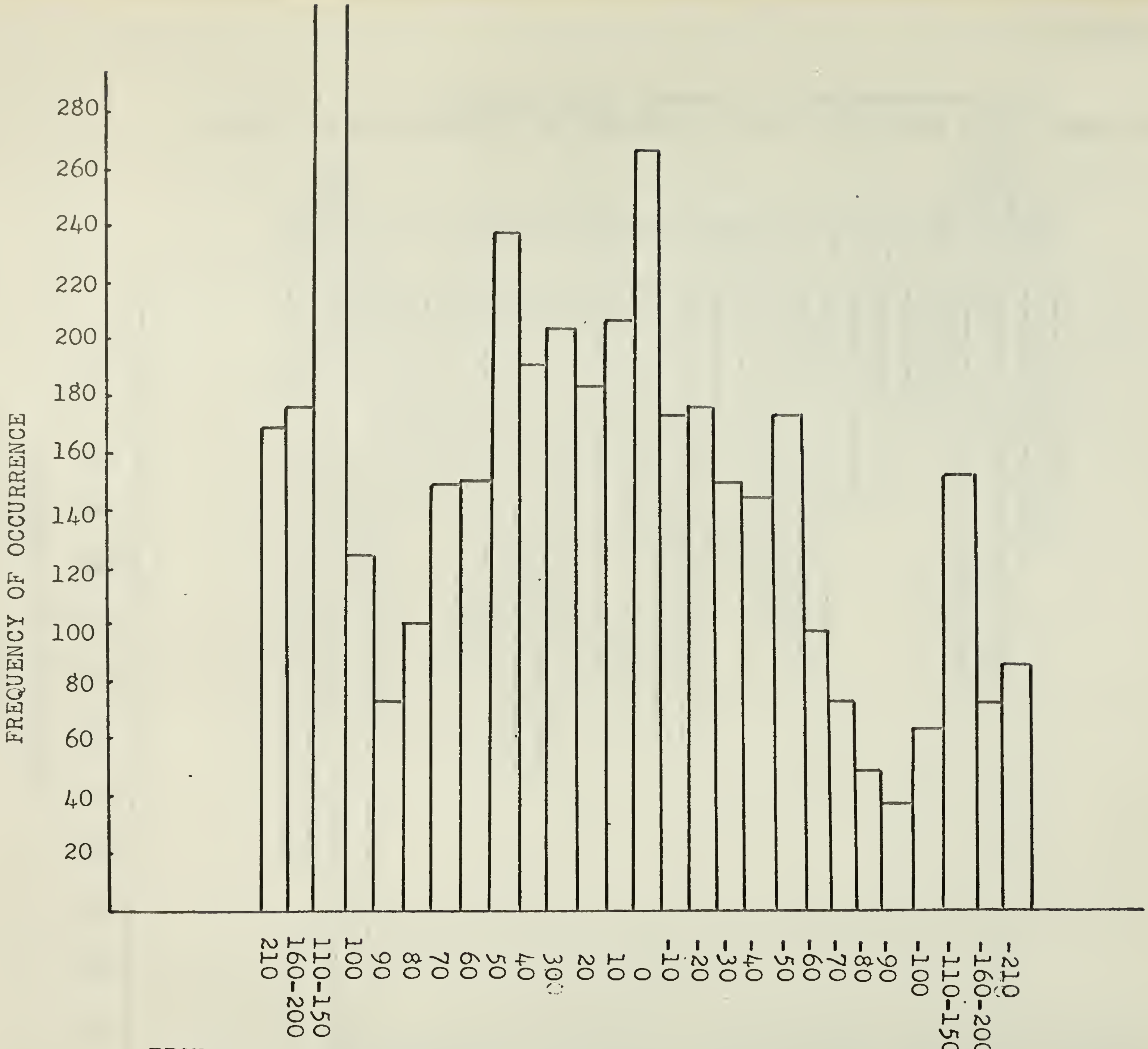


FIGURE 22 DISTRIBUTION OF ERRORS FOR THE FORECASTED MIXED LAYER DEPTH TOTAL PERIOD. (Based on 4010 observations)

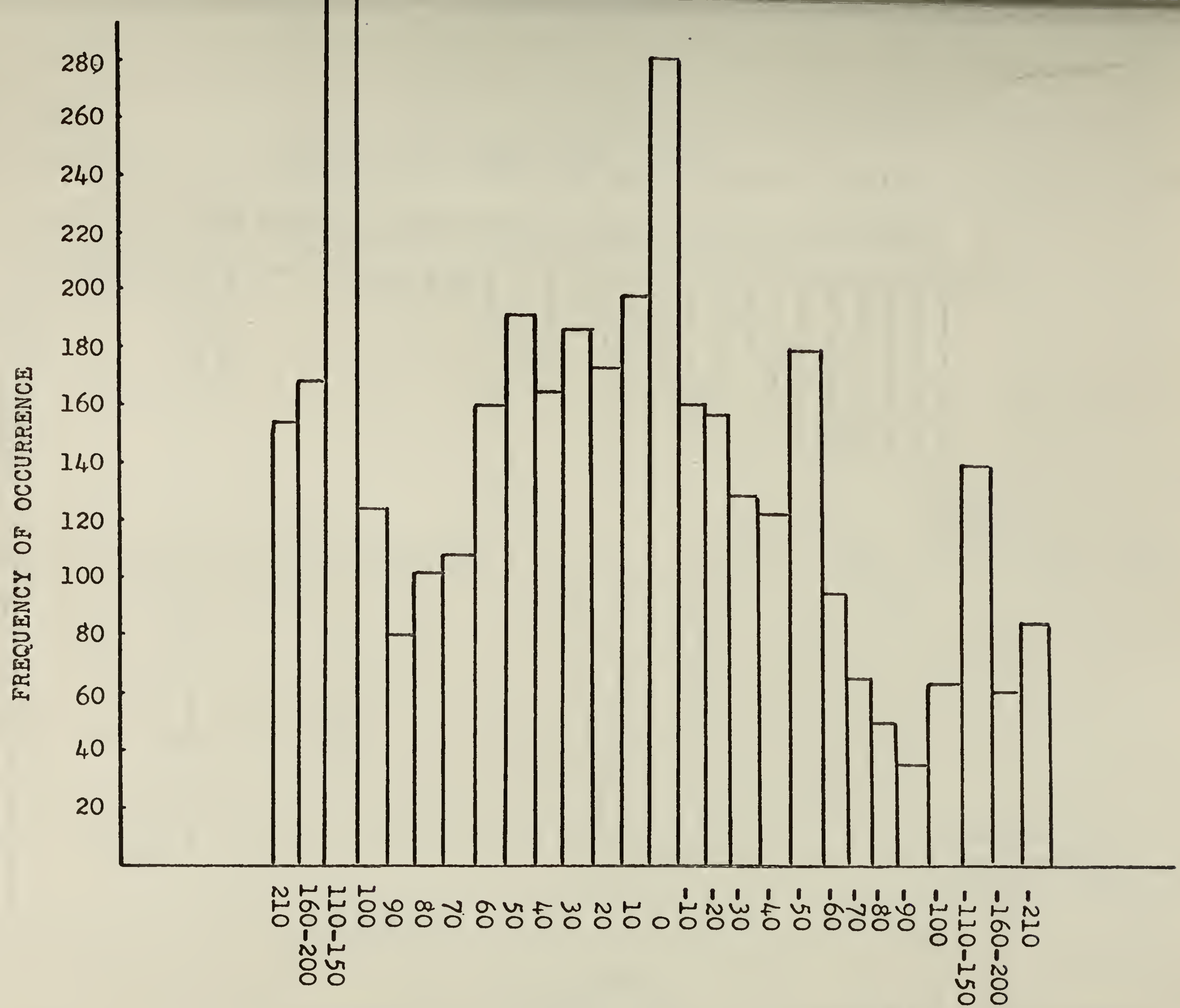


FIGURE 23 DISTRIBUTION OF ERRORS FOR THE ANALYZED MIXED LAYER DEPTH TOTAL PERIOD. (Based on 3740 observations)


FIGURE 24 DISTRIBUTION OF ERRORS OF GREATER THAN + 100 FEET FOR JANUARY 1966 FORECASTED MIXED LAYER DEPTH

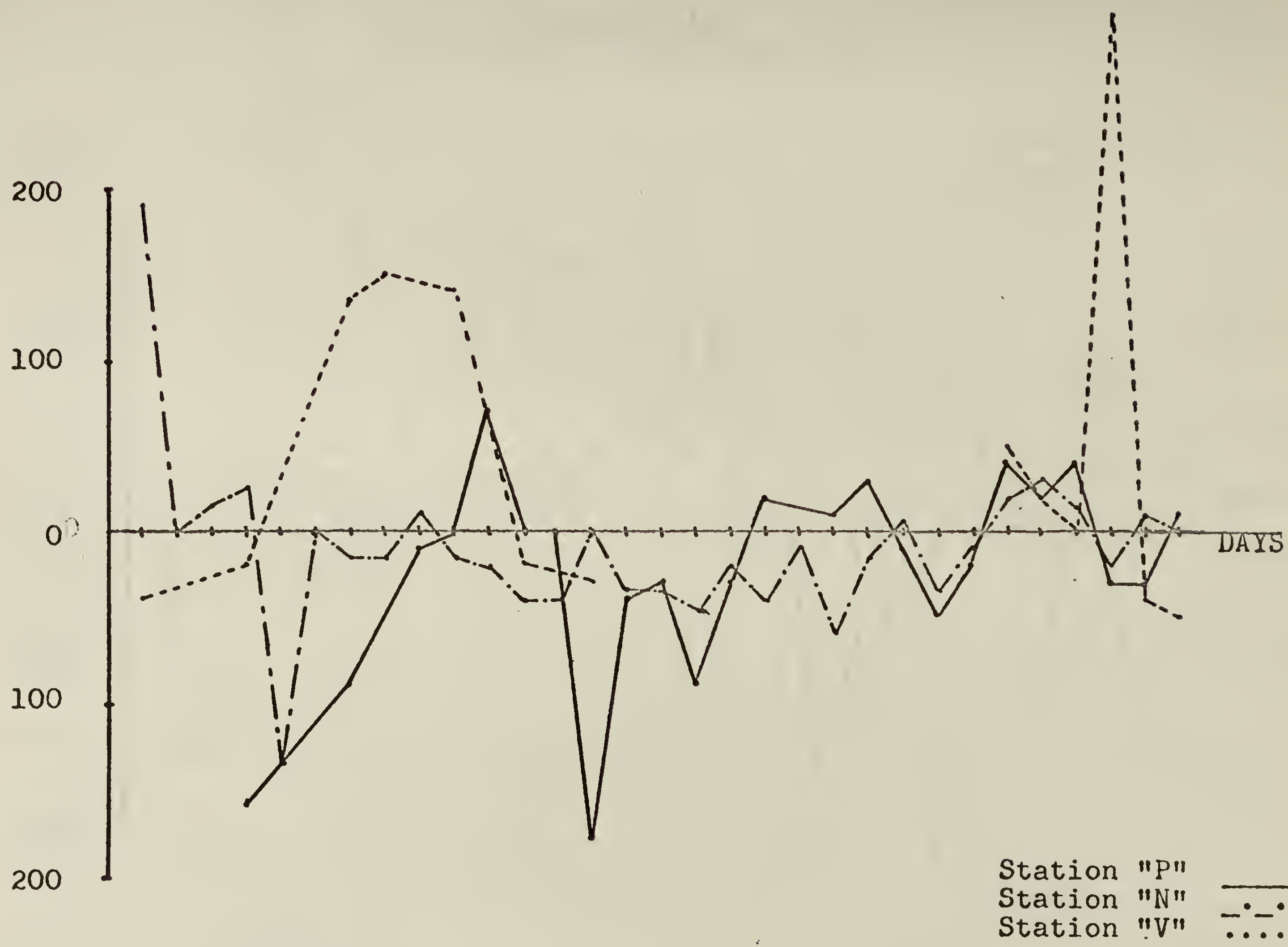


FIGURE 25

VARIATION OF ERRORS WITH TIME
OCTOBER 1965

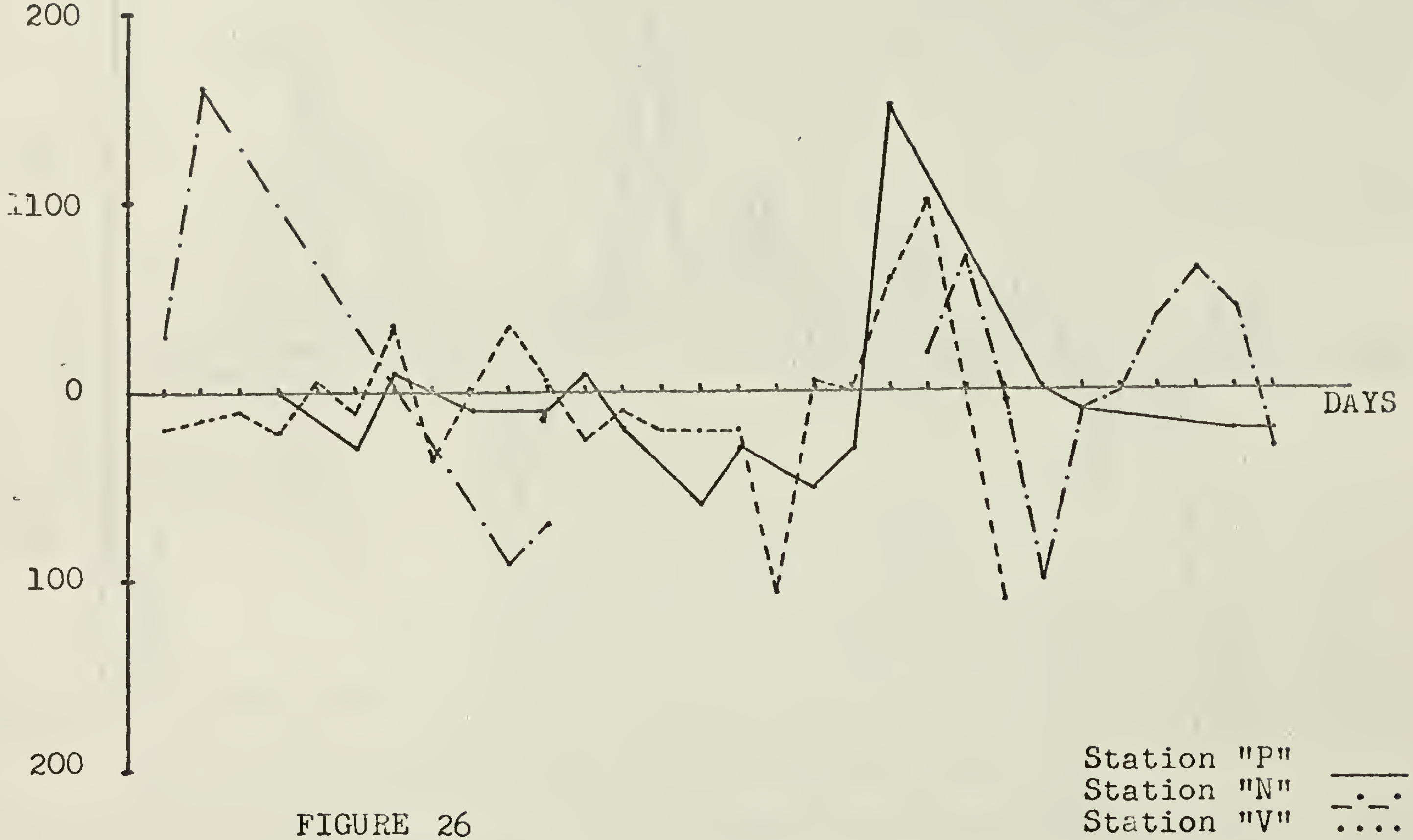


FIGURE 26

VARIATION OF ERRORS WITH TIME
NOVEMBER 1965

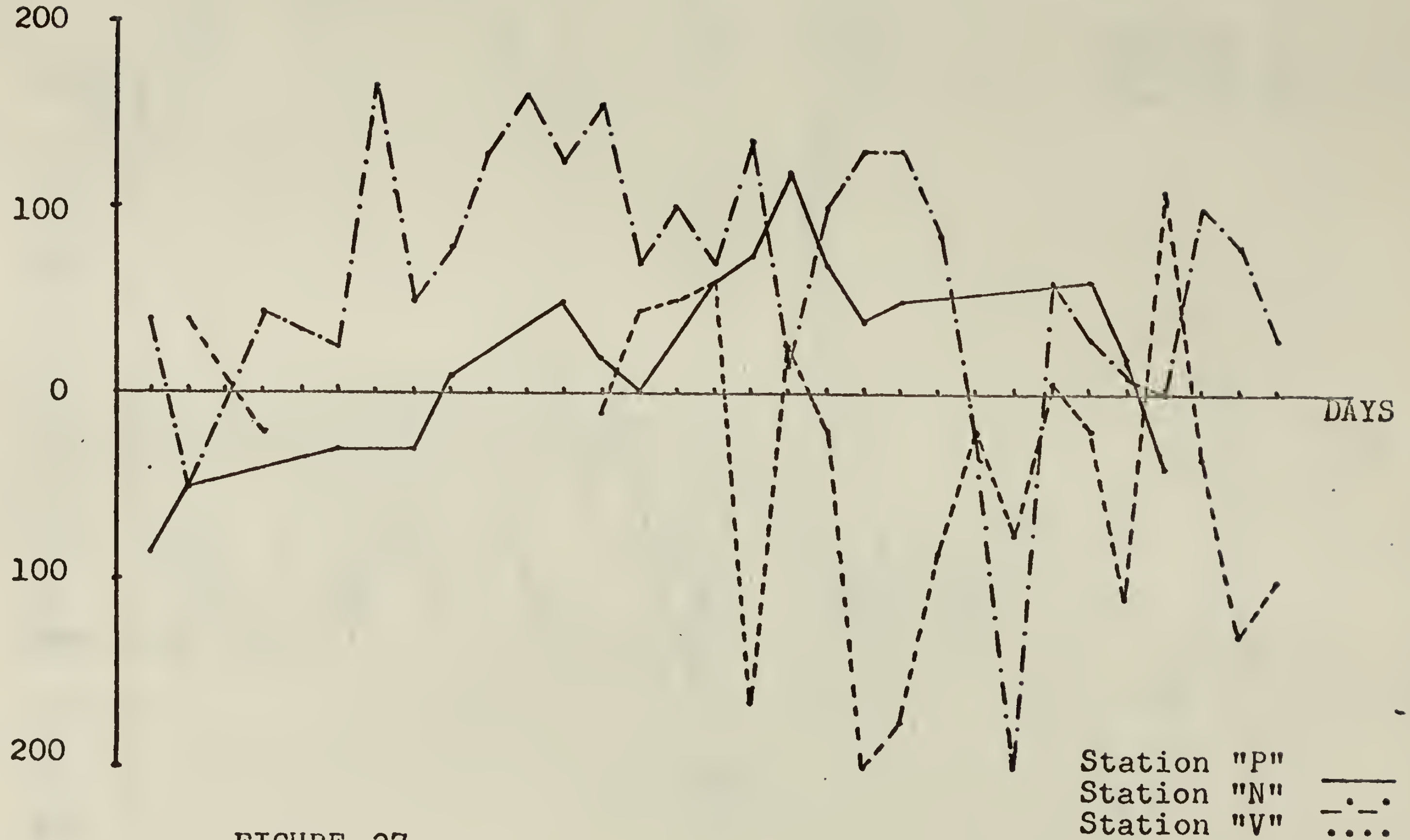


FIGURE 27

VARIATION OF ERRORS WITH TIME
DECEMBER 1965

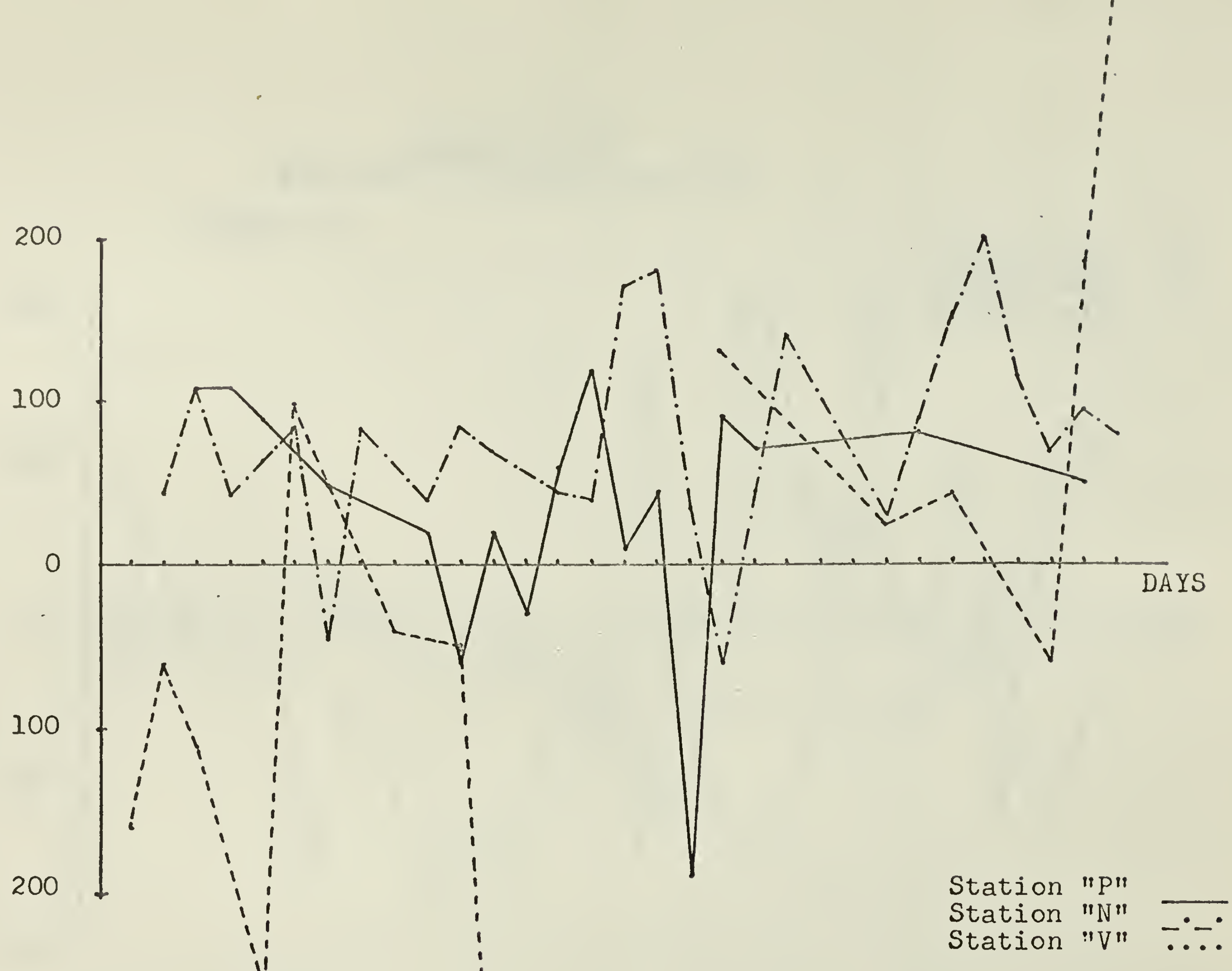


FIGURE 28

VARIATION OF ERRORS WITH TIME
JANUARY 1966

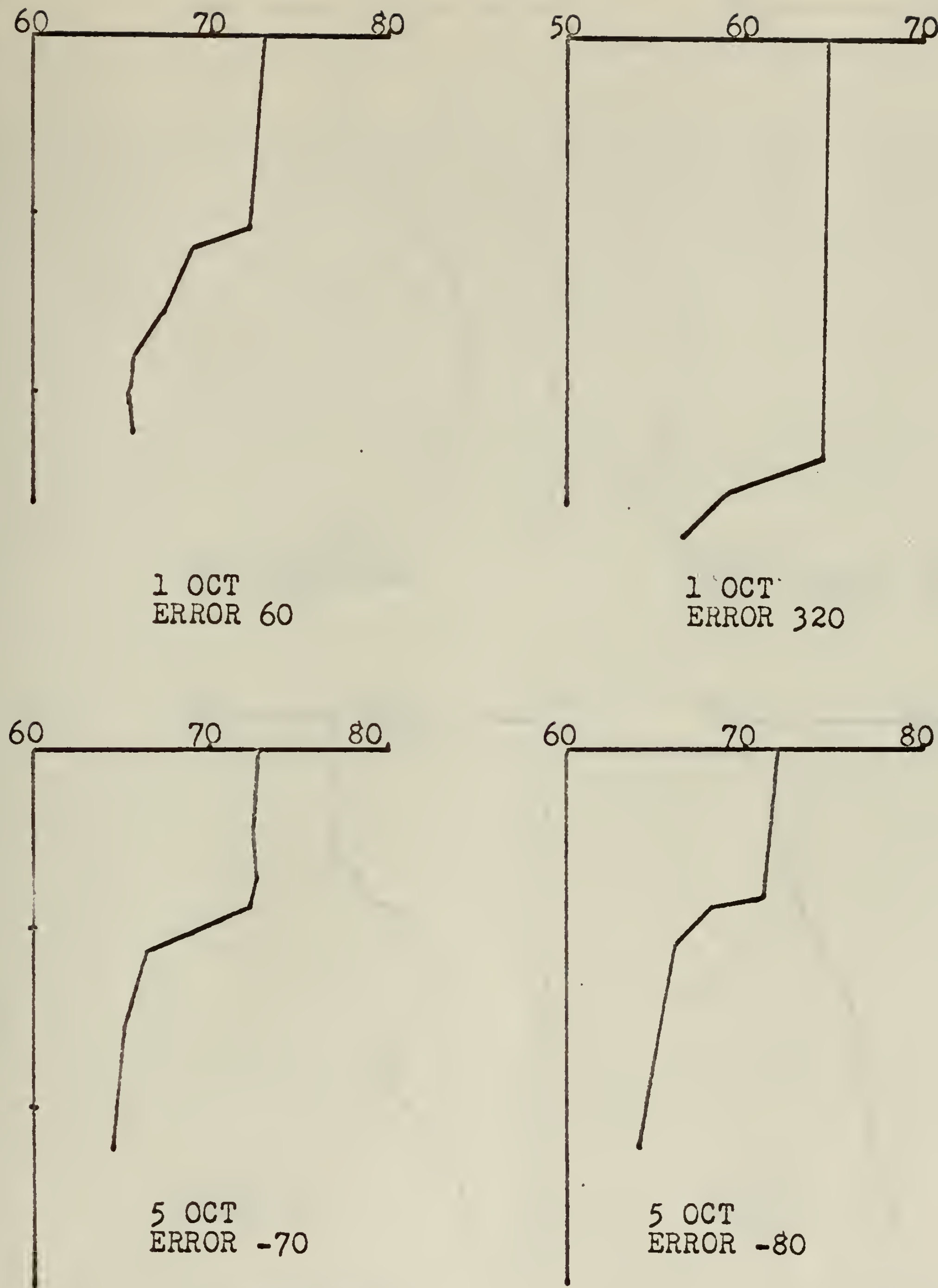


FIGURE 29

SELECTED BATHYS FOR THE DATES INDICATED


FIGURE 30

SELECTED BATHYS FOR THE DATES INDICATED

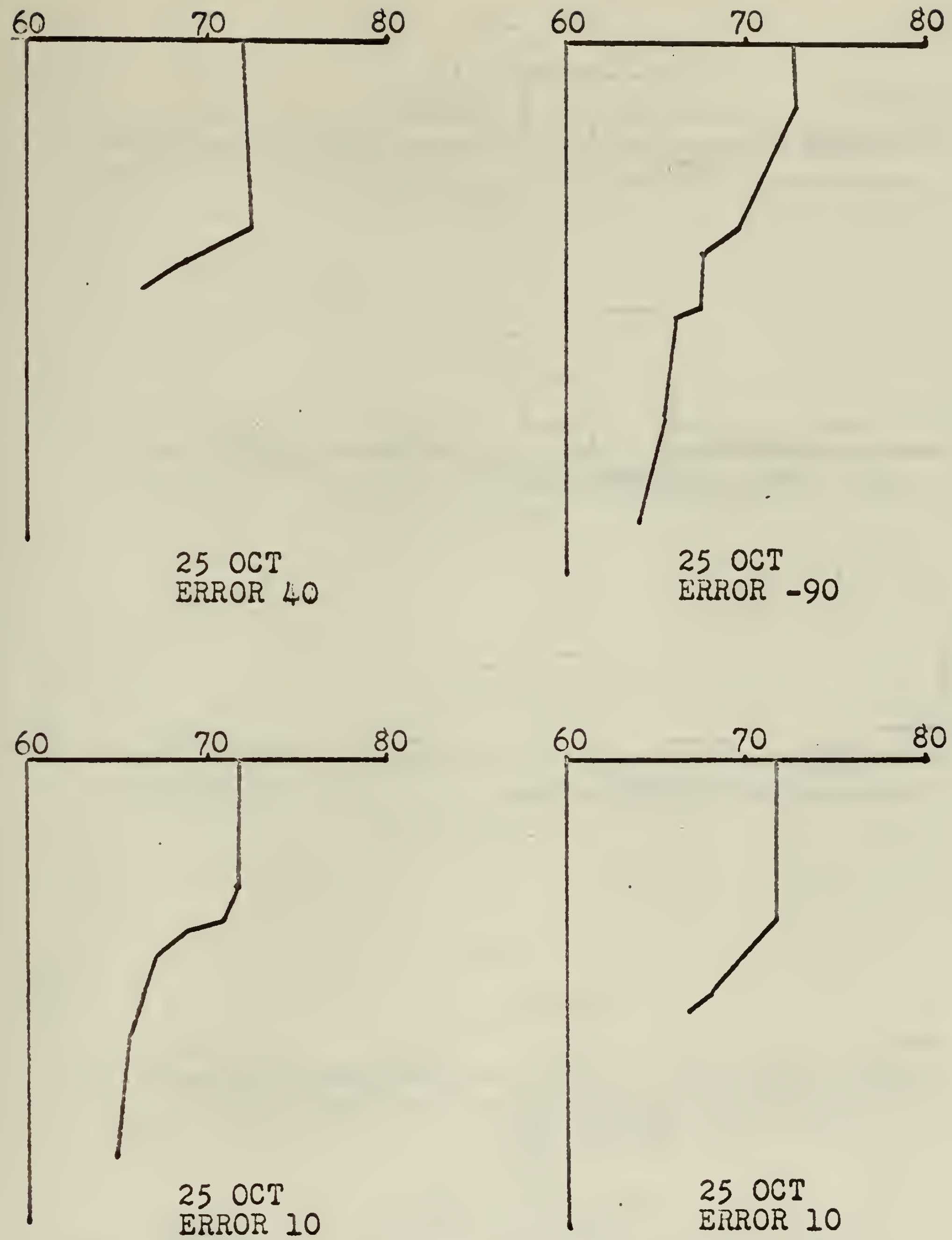


FIGURE 31

SELECTED BATHYS FOR THE DATES INDICATED

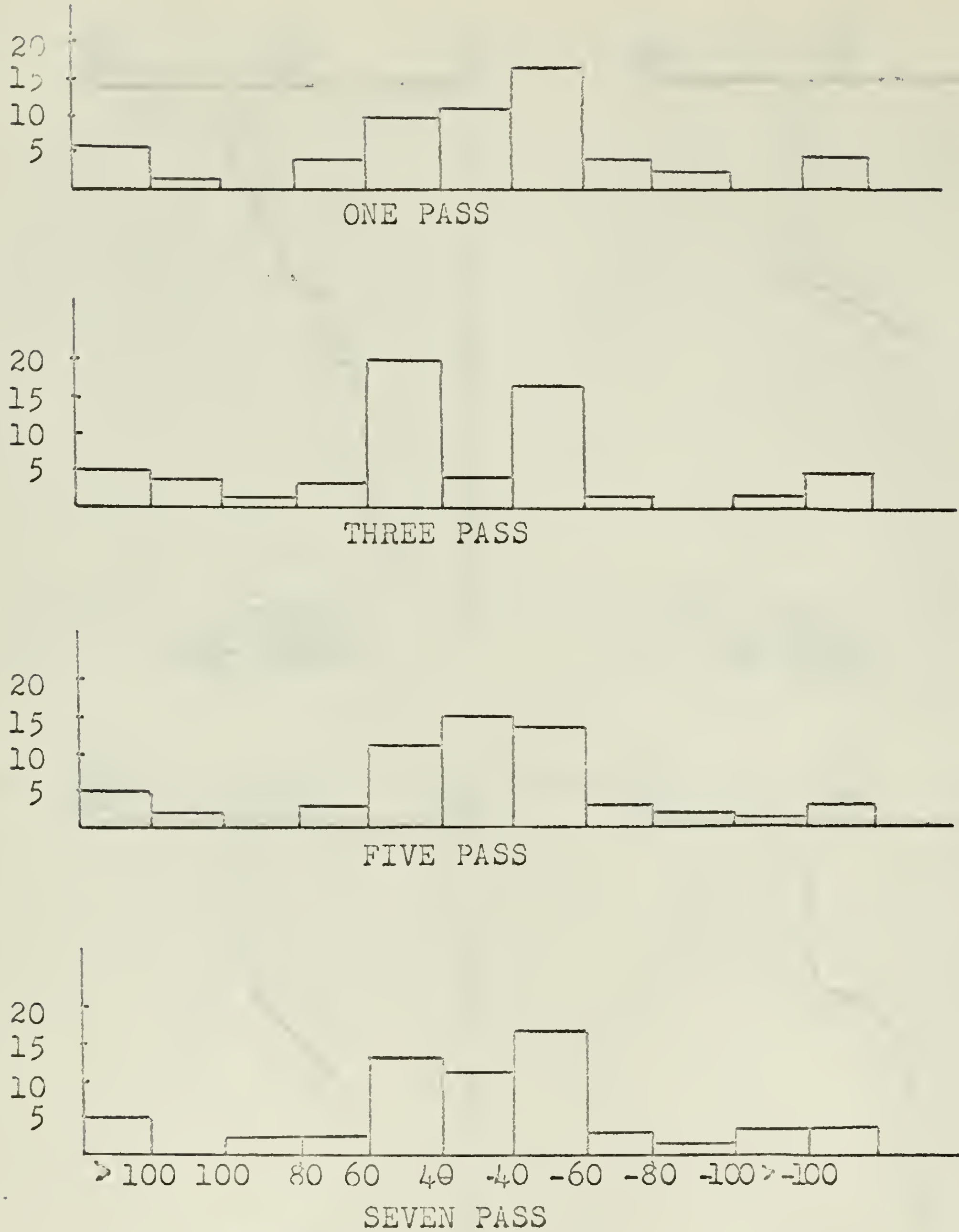


FIGURE 32 SPECIAL PROJECT

Frequency of occurrence of errors as the number of passes of the bathythermograph data is varied (Forecast of the Pacific area for 9 March 1966) (Based on 40 observations)

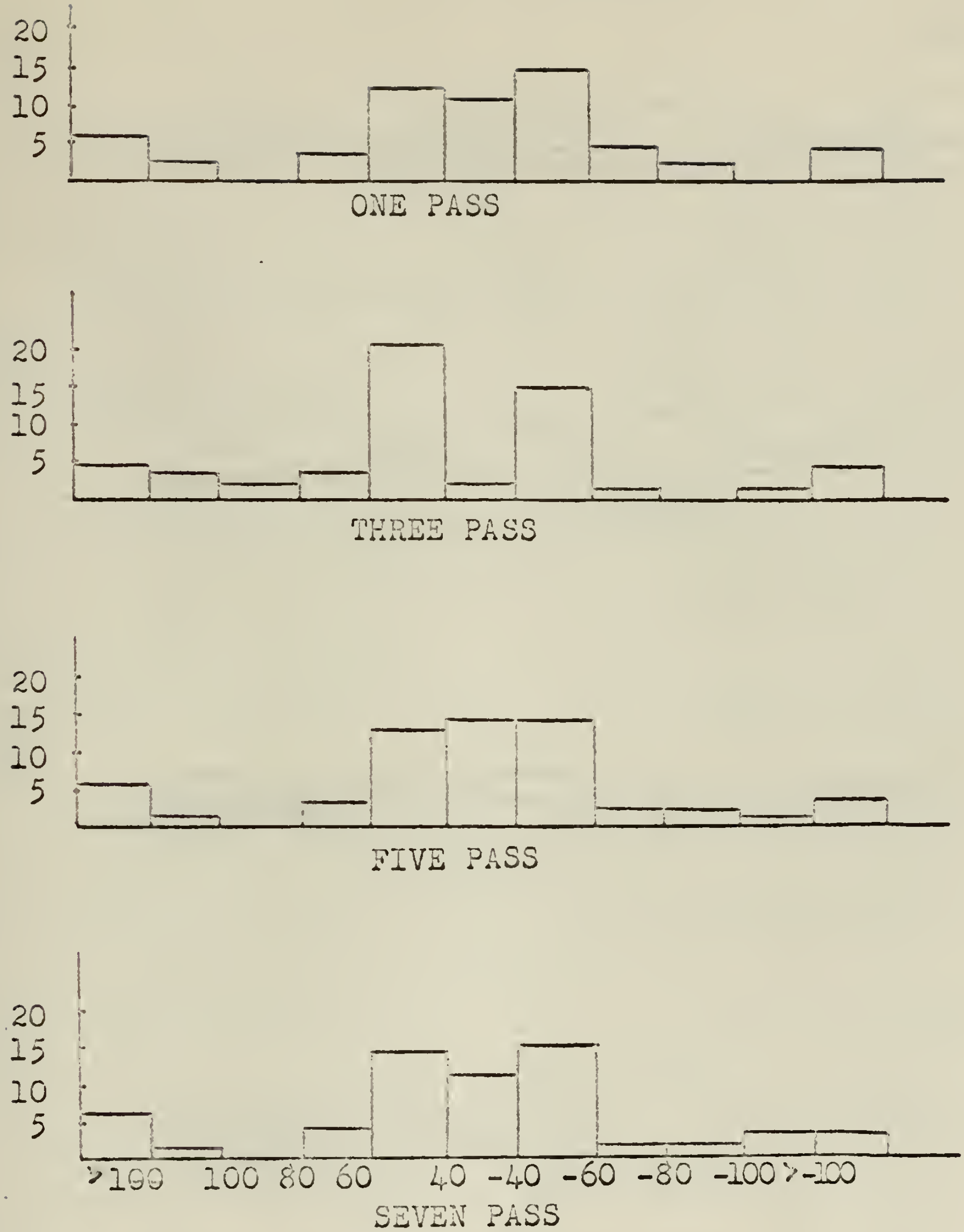


FIGURE 33 SPECIAL PROJECT

Frequency of occurrence of errors as the number of passes of the bathythermograph data is varied (Analysis of the Pacific area for 9 March 1966) (Based on 40 observations)

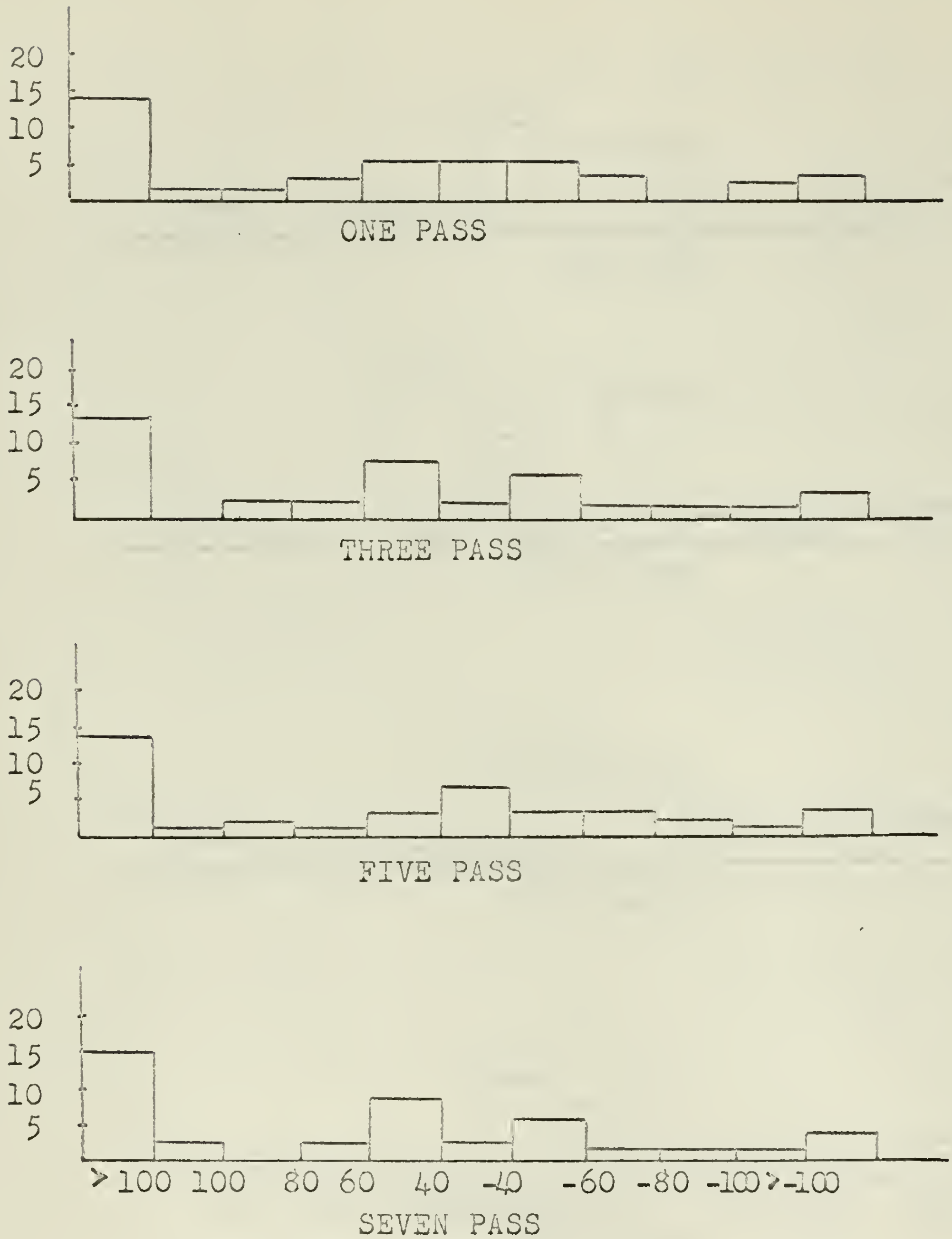


FIGURE 34 SPECIAL PROJECT
Frequency of occurrence of errors as the number of passes of the bathythermograph data is varied (Forecast of Atlantic area for 9 March 1966) (Based on 59 observations)

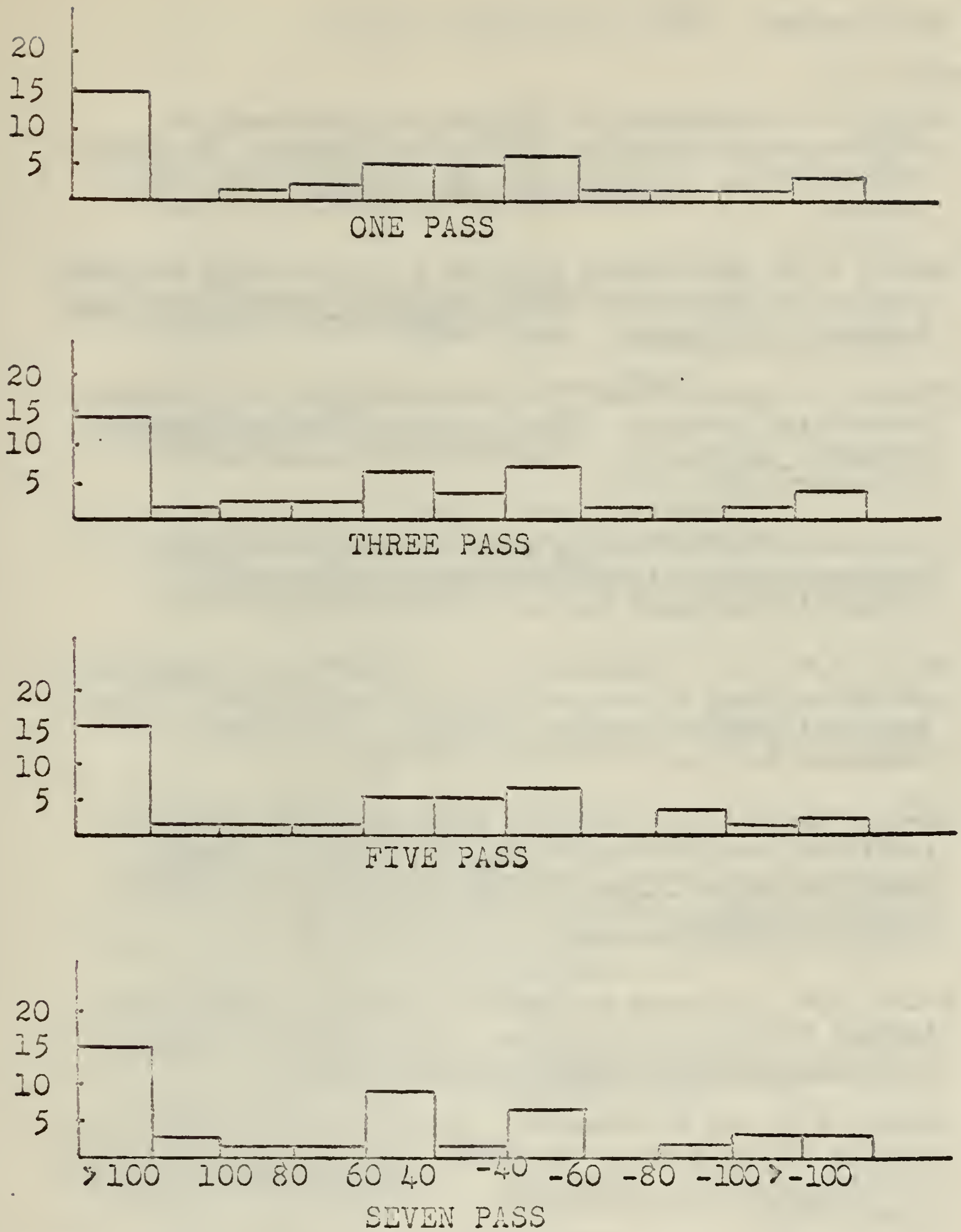


FIGURE 35 SPECIAL PROJECT
Frequency of occurrence of errors as the number of passes of the bathythermograph data is varied (Analysis of Atlantic area for 9 March 1966) (Based on 59 observations)

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10. Oceanographic analyses and forecasts for fleet support. Fleet Numerical Weather Facility, Monterey, California. Technical Memorandum No. 11. September, 1965.

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13. ABSTRACT


In 1962, Fleet Numerical Weather Facility started distributing mixed layer depth forecasts and analyses to the Fleet on an operational basis. The present method of computing this mixed layer depth is discussed and a verification is conducted for the months of October, November, December, 1965, and January, 1966, to determine its accuracy and usefulness to the Fleet.

The results show that 42 percent of the forecasted and analyzed values are in the excellent (± 40 feet) range, while 26 percent of the values are in the poor (greater than ± 100 feet) range. The distribution of errors indicates that the majority of positive errors occur in the Western Pacific, while the negative error concentration is in the Eastern Pacific. Conclusions indicate that 20 percent of the time the forecast will be detrimental to Fleet use.


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| BATHY | | | | | | |
| NUMERICAL ANALYSIS | | | | | | |
| VERIFICATION | | | | | | |

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